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Structure of the Triangle Zone in the Rocky Mountain Foothills near Coalspur, Alberta.

by

© Stephen T. Johnston

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Structure of the Triangle Zone in the Rocky Mountain Foothills near Coalspur, Alberta, submitted by Stephen T. Johnston in partial fulfilment of the requirements for the degree of Master of Science in Geology.

ABSTRACT

Triangle zones, which commonly occur along the external margins of foreland thrust and fold belts, are each underlain by a subhorizontal, blind, foreland-verging thrust that ends against a foreland-dipping, hinterland-verging thrust. These contemporaneous thrusts, active at the end of orogenesis, enclose an intercutaneous wedge that was displaced towards the foreland. This wedge may enclose or cut off remnants of older wedges, each of which once lay along the external margin of the belt.

The evolution of a triangle zone can be envisaged as follows. As each wedge moves towards the foreland, the width of the highest flat of the lower fault increases. This width is reduced by the development of new upper faults that are inside their predecessors and end downwards against the same lower fault. Eventually a new lower fault develops, usually beneath its predecessor. The upper fault of the new wedge may cut off some of the old wedge which then reverts to being part of the foreland. Alternatively, the new upper fault may coincide with or be outside its predecessor, in which case the new wedge incorporates all of the old wedge.

Near Coalspur, the triangle zone exposes the remnants of several wedges whose configurations conform to some of the above situations. The lower faults of two wedges follow coal seams. At the extremities of these wedges, the thickness of

each seam is up to 20 times the stratigraphic thickness. This thickening results from the vertical stacking of duplexes whose roof and floor thrusts lie within the seams.

ACKNOWLEDGEMENTS

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INTRODUCTION

The Rocky Mountain Foothills of central Alberta are underlain mainly by clastic wedge strata ranging in age from Late Jurassic to Paleocene. The strata were detached from their basement, deformed, and transported towards the northeast during the Laramide orogeny. Most of the deformation and displacement was associated with southwest-dipping, northeast-verging thrust faults that merged at depth with the basal detachment zone. Deformation tended to migrate from southwest to northeast so that, as a rule, the lower or more northeasterly of any two thrust faults is the younger.

The most external structure in the Foothills is generally a northeast-dipping, southwest-verging thrust fault. This fault ends at depth against the youngest southwest-dipping, northeast-verging thrust fault. These two contemporaneous faults, which were active at the end of orogenesis, enclose a northeast-tapering wedge of strata. Strata enclosed by the blind thrust, the northeast-dipping thrust, and by the youngest of the northeast-verging thrusts to intersect the topographic surface constitute the Triangle Zone (e.g. Gordy and Frey, 1975; Price, 1981; Jones, 1982; Teal, 1983; McMechan, 1985; Lawton, 1985). Recent structural studies (Charlesworth and Gagnon, 1985) have determined that a tectonically thickened coal seam in the Triangle Zone at Coal Valley, southeast of Coalspur, occurs at the extremity of an old wedge.

The purpose of this study was to examine the structure of the Triangle Zone in the Rocky Mountain Foothills near Coalspur. A better comprehension of the structural processes at work in the Triangle Zone is important for several reasons. Intercutaneous wedges, which are associated with the Triangle Zone, were probably the shallowest, most external structures throughout orogenesis. As such, the Triangle Zone is bound to have exerted considerable influence on topography and thus on sedimentation in the adjacent Foreland Basin. Also, the intercutaneous wedges appear to be small-scale equivalents of the wedges that separate obducted flakes from subduction zones (Oxburgh, 1972). A more complete knowledge of the Triangle Zone may therefore lead to a better understanding of some processes associated with plate tectonics.

From an economic point of view Triangle Zones are very important. In Alberta alone two major coal mines, including the Luscar - Sterco Coal Valley mine, and numerous oil and gas plays, including the Turner Valley field, are located within the Triangle Zone. Further exploration within the Triangle Zone would be aided if the principles controlling deformation there are better understood.

Finally there is one special reason for studying the Triangle Zone in Alberta. Triangle Zones, mainly because of their poorly exposed nature and the scarcity of marker horizons in their clastic wedge sequences, are less well understood than the more internal regions of Foreland Fold-and-Thrust Belts. As

mentioned above, the Triangle Zone in Alberta is characterized by the presence of coal seams. These seams, which make excellent marker horizons, have been and are being actively explored by coal companies. The resulting data from drillhole and open-pit mines provide information unavailable in most Triangle Zones.

This study was accomplished by:

1) expanding the Coal Valley drillhole and outcrop data base established by Gagnon (1982) to include the "Robb Trend" to the northeast, and the area along strike from Coal Valley to the northwest as far as the Yellowhead fire tower.

2) processing these data with the software package TRIPOD.

3) using a computer-based geometric modelling procedure similar to that used by Jones (1982) and Charlesworth and Gagnon (1985).

The Coalspur region is 200 km west of Edmonton (Fig. 1). The area is readily accessible from Nordegg via the Forestry Trunk Road, from Edson by Highway 47, and from Hinton by the Hinton-Robb road. The "Coal Branch" of the CNR runs from Edson through Coalspur where it splits into two lines: one extends southeast to Coal Valley while the other continues west to Cadomin.

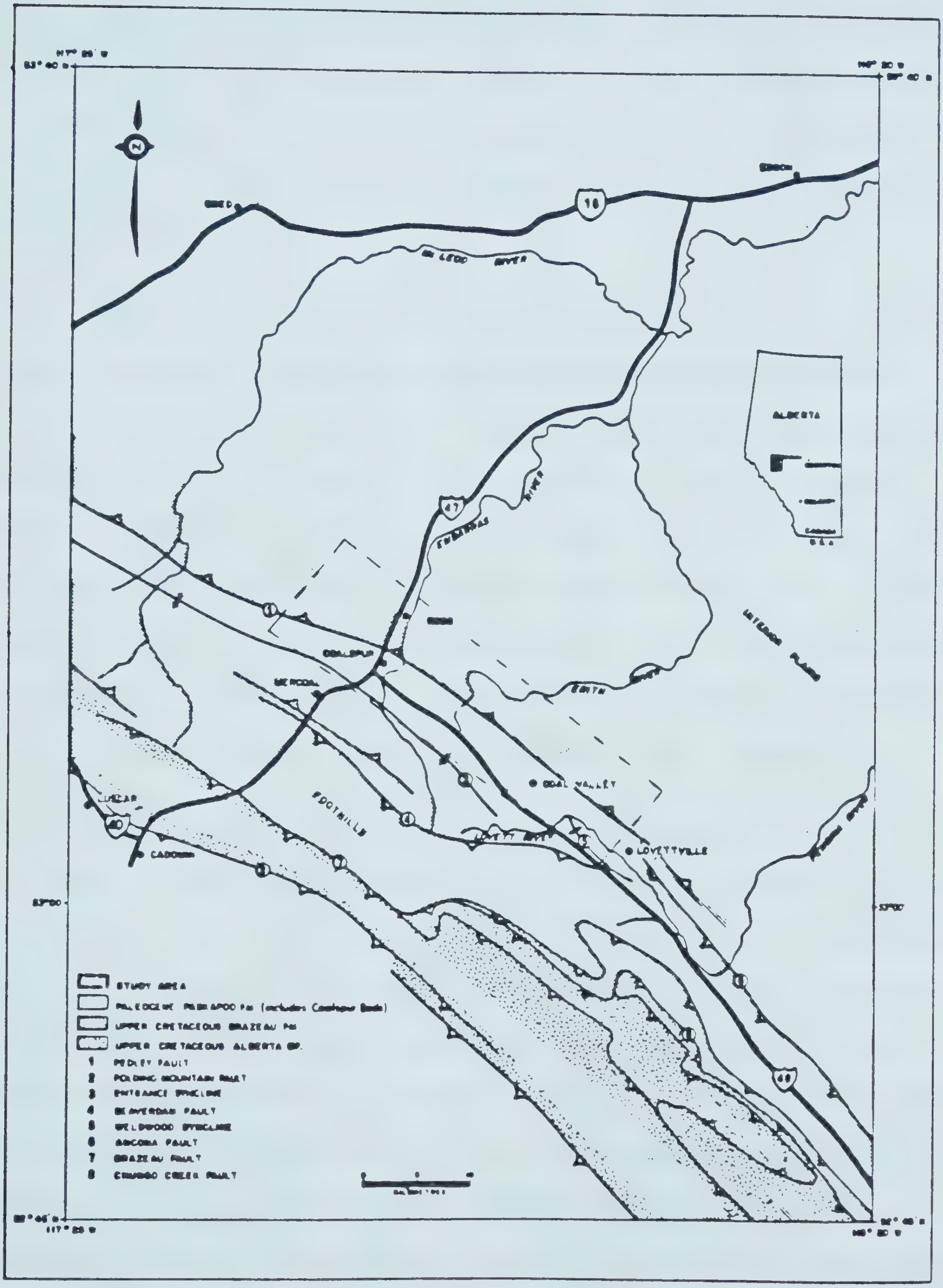


Figure 1. The Rocky Mountain Foothills in the Coalspur area (after Price et al., 1977).

Maximum elevations decrease from 1490 m at Coal Valley to 1220 m north of Yellowhead Tower. Local topographic relief increases from 25 m at Coal Valley to 200 m near Coalspur. The region is drained by the Pembina, Erith, Embarras and McLeod Rivers.

The earliest geological investigations of the foothills of west central Alberta coincided with the building of the Grand Trunk Pacific Railway. Dowling began mapping along the railway route into Jasper Park in 1907 for the Geological Survey of Canada. Prospectors had begun working in the area as early as 1906, discovering coal at Mountain Park and in the Coalspur area. In 1911 construction of the "Coal Branch" of the Pacific Railway began. This branch was built to provide access to the Coalspur and Mountain Park coal properties.

Increased access to the area was accompanied by an increase in geologic activity. Investigations were undertaken by Dowling (1909, 1922) and Stewart (1916) for the Geological Survey of Canada. Studies by Allan (1920), Allan & Rutherford (1923, 1924), and Rutherford (1925) were sponsored by the Scientific and Industrial Research Council of Alberta. These studies described the structure, stratigraphy and economic potential of the Coal Branch. MacKay (1943, 1947, 1949) produced a map of the external foothills providing more detail on the structure and stratigraphy of the area.

During the nineteen-fifties conversion of the railways from steam to oil denied the coal mines of their main

market. Mine closures in the Coalspur area began in 1952 and were complete by 1961 (Ross, 1974).

The opening of markets for thermal coal in Ontario and coking coal in Japan and South Korea during the seventies inspired a resurgence of both mining and geologic work in the area. The Athabasca map (Price et al., 1977) illustrated the regional structure of the central foothills. Alexander (1977) gave a preliminary description of the structure of the Mynheer coal seam at Coal Valley. Gagnon (1982) and Charlesworth & Gagnon (1985) examined in detail the structural evolution of the thickened Mynheer seam at Coal Valley. Jerzykiewicz & McLean (1977, 1980), McLean & Jerzykiewicz (1978), and Jerzykiewicz (1985) have discussed the sedimentological characteristics of the area.

DATA COLLECTION

INTRODUCTION

Any study of the Triangle Zone must take into account the very poorly exposed nature of the zone and the scarcity of marker horizons present in the underlying Upper Cretaceous and Paleocene strata. In the Coalspur area this problem is circumvented to a large extent by the presence of the Luscar - Sterco Coal Valley mine. The mine, which started production in the late seventies, has provided numerous artificial outcrops. As well, exploration conducted by Luscar - Sterco Ltd. has produced several thousand drillholes in the area. Most of these drillholes have been logged.

This chapter describes how these drillhole data were introduced into a data base and processed. It also includes a discussion of field data gathered in the field during the summer of 1984.

FIELD DATA

Six weeks of the summer of 1984 were spent collecting field data from the Coalspur area. Transportation was provided by a Ford pickup truck and a Suzuki RV90 trail bike. Due to heavy undergrowth throughout most of the field area, traverses generally coincided with cut seismic lines.

Outcrop positions were located in the field using 1:60-000 aerial photographs produced by the Alberta Department of Energy and Natural Resources. Outcrop locations were then

transferred to 1:12 000 topographic maps prepared by Luscar - Sterco Ltd. and Western Photogrammetry Ltd. Thirteen outcrops not covered by the 1:12 000 maps were located using 1:50 000 NTS topographic maps. Certain stratigraphic horizons, for example the Val D'or coal seam, were traced on the 1:60 000 aerial photographs using topographic features identified in the field.

Positional, lithologic and stratigraphic data were recorded on field sheets A and B. For a description of the formats of these sheets see Gagnon (1982). Descriptions of the variables and codes used for field sheet A can be found both in Gagnon (1982) and in Charlesworth (1981). All orientation measurements were made using a Freiberger structural compass and Silva Ranger compass. Bedding orientations were recorded as dip direction and dip. All azimuths were measured with respect to true north. At each outcrop where bedding is uniformly oriented as many as seven planar bedding orientations were taken. Where outcrops exposed fault planes or mesoscopically folded bedding planes, as many orientations as possible were taken.

Eastings and northings were recorded with respect to the Luscar-Sterco mine grid. The mine grid northing is oriented 45° 44′ 21" clockwise from true north. The mine grid is measured in feet from a reference point located southwest of the Luscar Sterco mine lease. A reference point located within the study area is the southeast corner of Legal subdivision 7 - Township

47 - Range 19 - West of the 5th Meridian. This reference point has a grid northing of 33,392.35 and a grid easting of 95,044.07.

DRILLHOLE DATA

Lithologic, stratigraphic and fault picks from 45 drillholes completed during the winter of 1976-77 were recorded. Picks were made using geophysical logs run in these drillholes. Most of the logs consisted of gamma, caliper, density and single point resistance curves on a scale of 2.5 cm to 3 m. These 45 holes were drilled along 7 lines between Coalspur and Sterco. These lines trend northeasterly and are about 1.5 km apart. Spacing of holes along the lines varied from less than 100 to over 1000 m.

Drillhole header data and overburden depth were recorded on field sheet C. On field sheet D lithologic, stratigraphic and fault picks were recorded using a code and down hole depth. One copy of sheet C was filled out for each borehole while one copy of sheet D was filled out for each pick. For a description of the format of all four sheets and the coding system used for recording the data see Gagnon (1982).

OTHER DATA

Outcrop data collected by Luscar-Sterco Ltd. and recorded on maps were introduced into the data base using the digitizing hardware and software available within the Department of Geology at the University of Alberta (see Fossey,

1985).

DATA PROCESSING

The outcrop and drillhole data accumulated during this study were added to the Coal Valley computer data base created by Gagnon (1982). This merging of data bases required that the coding system created by Gagnon for denoting stratigraphic, lithologic, and structural data be maintained throughout this study. All azimuths of structural data were converted to mine grid northing at this time. As well, UTM coordinates were referred to mine grid coordinates using the program CV-1 (Appendix 1).

Outcrop and drillhole data were stored, retrieved and processed using the software package TRIPOD (Charlesworth, 1981) available on the AMDAHL 580/5860 mainframe computer at the University of Alberta.

MAPS AND CROSS-SECTIONS

Analysis of deformed terrains using numerical computer-based techniques requires that the study area be divided into domains within which deformation can be considered cylindrical (see e.g., Cruden, 1968; Charlesworth et al., 1976). Due to the paucity of data and the highly irregular distribution of data points this method could not be applied throughout most of the study area. Where outcrop data were plentiful, such as along the Robb-Coalspur highway, domains, within which bedding can be considered to be cylindrically

folded, were established.

Down plunge cross-sections were found to be useful. Both outcrop and drillhole data were projected parallel to the local fold axis onto vertical planes oriented perpendicular to strike. Where strata were found to be essentially planar, such as in the hanging wall of the Pedley Thrust fault, data were projected along the line of strike onto a plane perpendicular to the strike line.

Where there were insufficient data to establish domains, such as between Coalspur and Sterco, several thin slices perpendicular to the regional strike, were delineated. These slices were positioned such that each slice contained one of the seven lines along which Luscar-Sterco had conducted drilling. The drillhole data and any outcrop data contained within the slices were then projected horizontally along a line parallel to strike. Although fold axes in the study area tend to exhibit a general southeasterly plunge, the plunge is never more than a few degrees and is often sub-horizontal. Moreover, the distance any one data point was projected was generally less than 250 m. Horizontal projection therefore did not produce significant errors.

Maps of outcrop and drillhole collar locations were produced using TRIPOD. These were used to verify outcrop and drillhole collar coordinates, to delineate domains, and to help choose cross-section locations.

The construction of a geologic map was also greatly facilitated by these maps. The surface traces of stratigraphic contacts, faults, and the axial traces of folds were located with the aid of the available outcrop data. The intersections of the traces of these features with the topographic surface as seen on cross-sections were also used to help position surface traces.

STRATIGRAPHY

INTRODUCTION:

Correlation from one borehole to the next was of vital importace to this study. Of the 3600 m of strata exposed in the study area the only known marker horizons are one tuff and a 300 m section of strata containing 8 coal seams. This chapter describes the major formations present in the study area and concentrates on these few marker horizons.

No new information is presented here. The coal stratigraphy has been studied in detail by geologists on the staff of Luscar - Sterco Ltd. (unpublished work). A simplified compilation and summary of their work is presented here. Detailed descriptions of the stratigraphy and of all outcrops mentioned in this chapter can be found in Jerzykiewicz (1985), Jerzykiewicz and McLean (1977, 1980), and McLean and Jerzykiewicz (1978).

Strata exposed in the study area belong to the Saunders Group of late Cretaceous to Tertiary age. The Saunders Group consists of up to 3600 m of synorogenic continental clastics deposited in the Foreland basin which developed east of the Rocky Mountains during orogenesis (Jerzykiewicz, 1985). The group exhibits a large scale cyclicity defined by the presence of 6 cyclothems. Each cyclothem consists of a lower sequence of stacked channel sandstones and an upper sequence of mudstones with coal intervals. Ash beds, volcanic chert beds,

and bentonites are useful marker horizons.

The Saunders Group has been divided into three mappable units. These are, in ascending order, the Brazeau, Coalspur and Paskapoo Formations (Fig. 2).

1) The Brazeau Formation

The Brazeau was first described by Malloch (1911) in the Bighorn Coal Basin between the North Saskatchewan River and the Brazeau River. The formation, of Campanian to Maastrichtian age, conformably overlies the marine Wapiabi Formation. A complete section of the Brazeau Formation outcropping along the Blackstone River has a total thickness of 960 m. The Blackstone River section is located approximately 70 km south-southeast of Coal Valley. The Brazeau Formation is dominantly a sequence of interbedded continental sandstones, siltstones and mudstones. The sequence has an overall cyclicity defined by the presence of four cyclothems (Fig. 2).

The lower half of each cyclothem is characterized by the occurrence of vertically stacked channel sandstones. These sandstones often exhibit abrupt scoured bases, are usually cross-bedded, fine to medium grained, tan to light grey in color, and weather brownish-orange. The inclusion of lignitic and chert fragments in the sandstones often results in a salt and pepper texture.

Channel lag conglomerates present within the sandstones contain spheroidal, well rounded, quartzite and chert pebbles

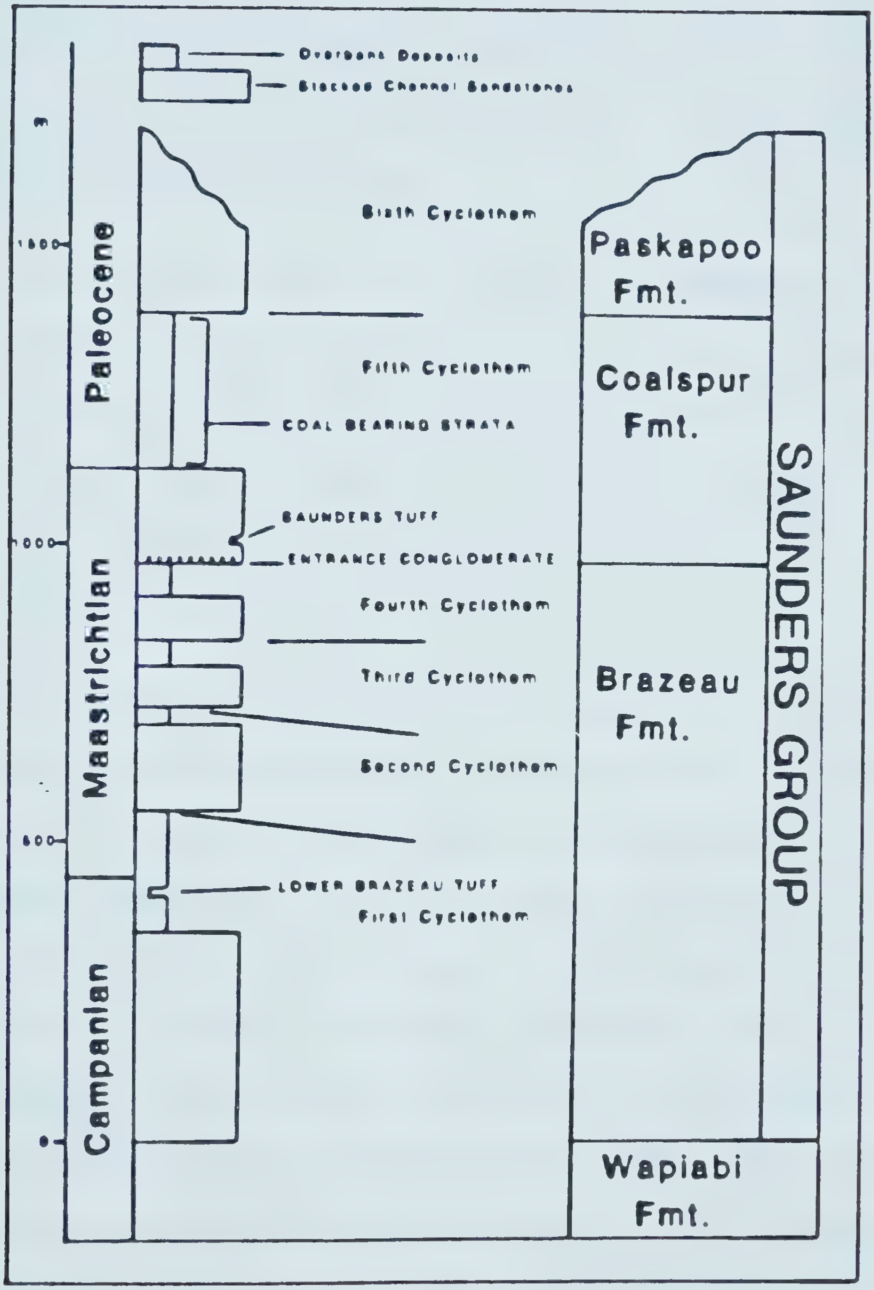


Figure 2. Stratigraphic column of the Saunders Group (after Jerzykiewicz, 1985).

and usually grade upwards into cross-bedded sandstones. Conglomeratic horizons are more extensive within the lower Brazeau and exhibit greater lateral continuity. These conglomerates tend to be moderate red in color and are occasionally coarser grained.

Brazeau mudstones, which occur predominantly in the upper parts of each cyclothem, often contain large quantities of disseminated silt, vary in color from grayish purple to pale olive and are usually massive. Fine laminations, desiccation fractures, and nodules are occasionally present. Fossilized plant remains are extremely common.

Bentonitic horizons are not uncommon in the Brazeau and are usually found associated with carbonaceous shales and mudstones. These thin horizons are occasionally finely laminated, sometimes displaying convolute bedding and water escape structures. They range in color from very light gray to pale greenish yellow. The most notable of these tuffs occurs approximately 440 m above the base of the Brazeau Formation on the Blackstone River (Jerzykiewicz, 1985). The tuff is characterized by a 10 to 15 m horizon of interbedded bentonitic material, silicified tuff, and alternating bands of light and dark lamina. This tuff is correlative with the silicified tuffs described by Jerzykiewicz and McLean (1977) that outcrop near Coal Valley (Jerzykiewicz, 1985).

2) The Coalspur Formation

Overlying the Brazeau Formation is the Coalspur Formation. This formation has been interpreted as one large cyclothem (Jerzykiewicz, 1985). The most striking characteristic of the formation is the presence of 7 major coal seams in the upper half of the cyclothem.

The Entrance Conglomerate forms the base of the Coalspur Formation. While the unit has been described as a "distinct and useful unit" (McLean and Jerzykiewicz, 1980), no recognizable outcrop of the conglomerate exists within the study area. The stratigraphic interval from the top of the conglomerate to the base of the Mynheer coal seam, the oldest coal seam in the Coalspur Formation, has been measured as 275 m in the Wawa map area (McKay, 1943) and as 245 m in the Saunders map area (Erdman, 1945). For the purposes of this study the base of the Coalspur Formation is defined as occurring 300 m beneath the base of the Mynheer seam throughout the study area. This interval is characterized by medium grained, grey to tan, salt and pepper textured sandstones interbedded with dark green to brownish mudstones.

The Saunders Tuff, a 5 m thick horizon of interbedded bentonite and silicified tuff, occurs 30 m above the base of the Coalspur Formation (Sanderson, 1931). The particular outcrop of tuff near the Coalspur railway station described by Sanderson no longer exists. A tuffaceous horizon which may be correlated with the Saunders tuff was located northwest of

Coalspur.

The upper half of the Coalspur Formation is between 225 m and 300 m thick and contains seven identifiable coal seams. These seams are, in ascending order, the Mynheer, Lower Silkstone, Upper Silkstone, Markers, McLeod, Arbour and Val D'or (Fig. 3).

The Mynheer seam is underlain by 2 to 3 m of interbedded coal, carbonaceous mudstone, and bentonite. The coal seam varies from 15 m thick at Mercoal, 10 km. west of Coalspur, thinning to 4 m at Coal Valley and Robb. The seam degenerates to stringers of coal northwest of the McLeod River and southwest of the Pembina River (R.F. Engler, pers. comm., 1985).

About 44 to 79 m higher up in the section are the Lower and Upper Silkstone seams, also known as the Bourne and Wee seams. The two seams are generally found within 8 to 20 m of each other. The Lower Silkstone seam is usually a little less than 1 m thick and is contained within two 0.5 m bentonites. The Upper Silkstone seam thins from 3.5 m southwest of Coal Valley to 1.5 m along the McLeod River (R.F. Engler, pers. comm., 1985).

The Marker seams, 70 to 150 m above the Upper Silkstone seam, are characterised by four major subseams over a 7 m interval near the McLeod River. This interval is also known as the McPherson seam. Near Coal Valley the subseams degenerate

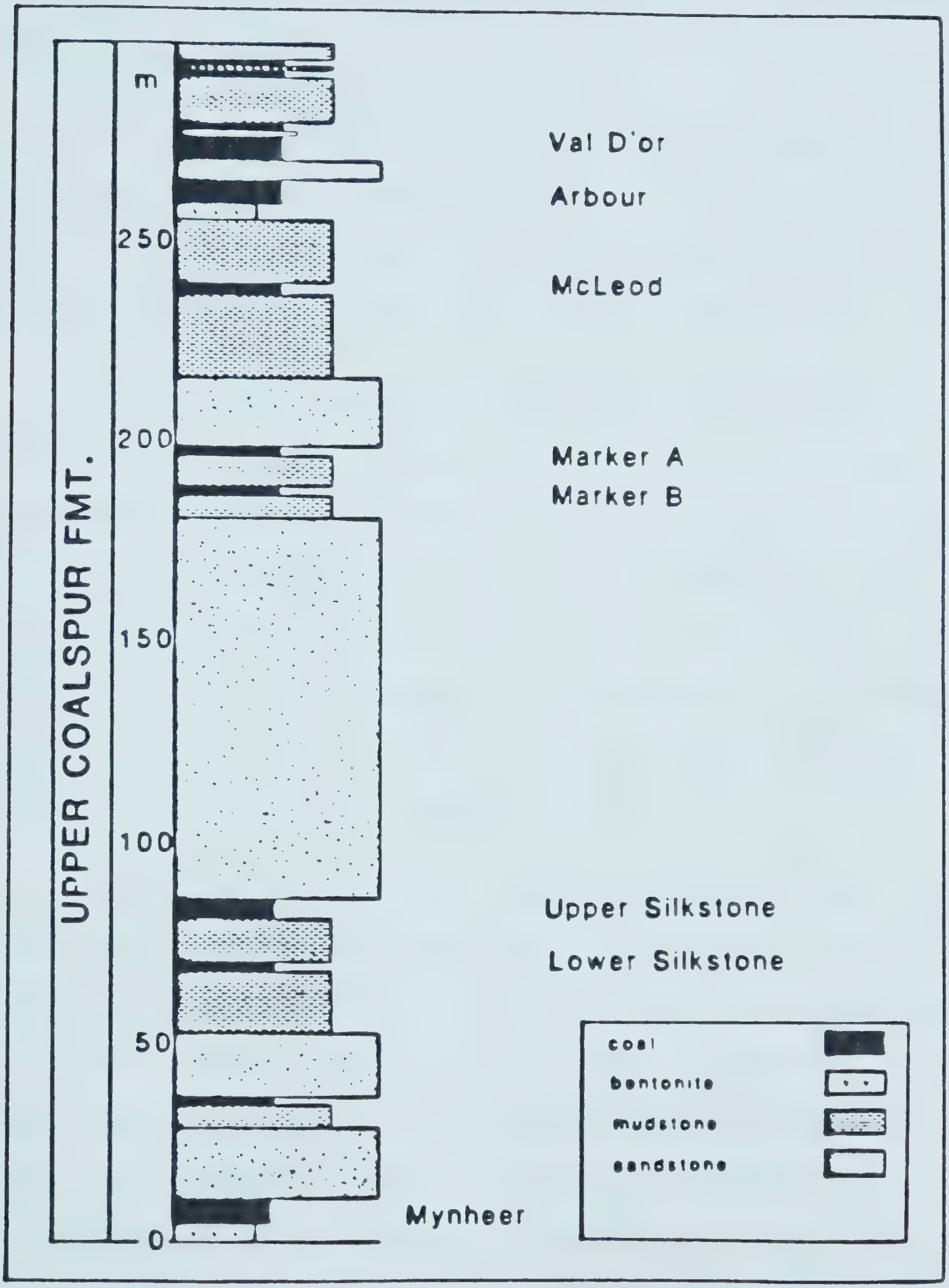


Figure 3. Stratigraphic column of the upper half of the Coalspur Formation.

into two seams known as Marker B and Marker A (R.F. Engler, pers. comm., 1985).

The McLeod seam is only recognizable between the McLeod River and Robb. The "seam" is really three thin coal horizons over a 3 m interval. South of Robb the seam is characterized by 2 m of carbonaceous shale (R.F. Engler, pers. comm., 1985).

The Arbour seam is the next major coal interval in the Coal Zone. The seam ranges from 3 to 10 m in thickness and is dominated by a series of bentonite and mudstone partings. The Arbour seam is underlain by the Arbour Bentonite. The bentonite is always within 4 m. of the coal seam and ranges from 1 m to 3 m in thickness. The bentonite is extremely soft, rarely outcrops, but is usually identifiable on bore hole gamma logs (R.F. Engler, pers. comm., 1985).

Above the Arbour lies the Val D'or coal seam. The Val D'or is 28 m above the Arbour near Coal Valley. This interval decreases to the north until just north of Coalspur where the two seams coalesce. The Val D'or seam is generally about 8 m thick, consisting of 8 to 10 individually correlatable coal bands. The largest of these partings is composed of .5 to 2.0 m of sandstone which divides the seam into a lower two thirds and an upper third. The base of the Paskapoo Formation occurs 0 to 15 m above the top of the Val D'or seam. Within this interval two thin coal horizons have been observed (Jerzykiewicz, 1985).

Each coal seam has a distinct signature on geophysical logs run in drillholes. Due to the very limited amount of outcrop present within the study area, the picking of these seams on logs is one of the most important tools available for correlation and structural analysis. Gagnon (1982), Charlesworth and Gagnon (1985) relied heavily upon these picks, as does this study. It is important then to emphasize that there are limitations to this method.

As pointed out by McLean and Jerzykiewicz (1980), "lateral variability in facies type and thickness is the rule in the Upper Cretaceous-Tertiary sequence of the Coal Valley area." Correlation of individual sandstone or shale units from one borehole to the next is suspect under these conditions. This limits correlation to the coal seams. Over the entire study area, the highly dynamic state of the surrounding sediments make it unreasonable to assume that the coal seams are static with respect to facies changes. This is hinted at by the pinching out of the McLeod seam, and by the Marker seams which change character from four seams near Robb to two seams near Coal Valley. In many drillholes the Marker seams are not present at all. This is also true of the Silkstone seams. Where these seams are not present it is probable that they were either not deposited or were later eroded by an active channel. It is unlikely that any of the seams were immune to these effects. Where a seam does not have the characteristic internal stratigraphy usually associated with that seam, errors of recognition are certain to occur. The

similarity of log signatures of different seams can also cause problems of seam identifacation.

The Coalspur beds house the Cretaceous-Tertiary boundary. Paleobotanical studies (Bell,1949) determined that the Mynheer seam was earliest Paleocene, while Eliuk (1969) determined palynologically that the Entrance Conglomerate was latest Cretaceous. This is in agreement with other more recent palynological work placing the Cretaceous-Tertiary boundary within the lower Mynheer carbonaceous shales (Mclean and Jerzykiewicz, 1980; Jerzykiewicz et al., 1984). The Cretaceous-Tertiary boundary iridium anomaly occurs in the bentonites and carbonaceous shales immediately beneath the Mynheer seam.

3) The Paskapoo Formation

The Paskapoo Formation was first described by Tyrell (1886). The base of the Paskapoo Formation coincides with the first occurrence of a prominent sandstone above the top of the highest major coal seam in the Coalspur Formation, an interval of 0 to 15 m. Within the study area the top of the Paskapoo Formation is always eroded. The maximum known thickness of the formation is approximately 500 m (Fig. 2).

The portion of the Paskapoo Formation preserved within the study area represents the lower part of the sixth and youngest of the Saunders Group cyclothems. The formation is predominantly characterized by thick, vertically stacked,

coarse to medium grained sandstone. The sandstones are light grey to yellow in color, weather to an orange-brown, and are often cross-bedded. Minor mudstone beds and rare coal seams and tuffaceous horizons are also present. Often the base of the Paskapoo Formation is marked by a very thin yet persistent cobble conglomerate. The conglomerate was observed to have a maximum thickness of only 0.5 m (Jerzykiewicz, 1985).

STRUCTURE

INTRODUCTION

The unusual geometry of the Triangle Zone has long interested structural geologists. However, poor exposure in the outer Foothills has made most attempts to draw balanced cross-sections through the area largely interpretive. Even in the Coalspur area, where there is considerable outcrop and drillhole data, a clear understanding of the structure is difficult. To limit the number of possible interpretations of the data, a computer-modelling procedure was used to predict structural configurations within the Triangle Zone. This chapter presents some of these predicted structural configurations. The structure of the Triangle Zone in the Coalspur area is then shown to resemble some of the predicted configurations.

The Cretaceous and Tertiary Saunders Group, which underlies the Coalspur region, is exposed in two major structures within the study area: the Entrance Syncline in the southwest and the Pedley Thrust sheet to the northeast. The Entrance Syncline is a broad open fold that plunges gently to the southeast. The fold can be traced 75 km along strike to the northwest, all the way to the Athabasca River. The Pedley Thrust sheet is underlain by the northeast-dipping, southwest-verging Pedley Thrust, apparently the upper fault of the youngest intercutaneous wedge in this part of the Foothills. The hangingwall strata include the Upper Coalspur

Formation. These strata dip northeast, probably parallel to the Pedley Thrust, and lie in the southwest limb of the Alberta Syncline.

In the study area only the northeast limb of the Entrance Syncline outcrops. This limb, which exposes the Upper Coalspur Formation, houses two major northeast-verging thrust faults. These are the Coal Valley and Coalspur thrusts and they are contained within the Mynheer and Val D'or coal seams, respectively. Originally, both these faults ended to the northeast against northeast-dipping, southwest-verging thrust faults and each acted as the lower bounding faults of seperate intercutaneous wedges.

The evolution of the Triangle Zone in the Coalspur region can be viewed as the result of the emplacement of a series of intercutaneous wedges, including the Mynheer, Val D'or, and Pedley wedges. At least one other wedge, the Lower Brazeau wedge, was also involved in the development of the triangle zone.

INTERCUTANEOUS WEDGES AND THE TRIANGLE ZONE

The essential features of an intercutaneous wedge are illustrated in the synthetic, computer-generated, model cross-sections of Figure 4. The way in which these cross-sections are constructed is described in Charlesworth and Gagnon (1985). In these and all other east-west transverse cross-sections, the thrust belt strikes north-south with the

(a)

(b)

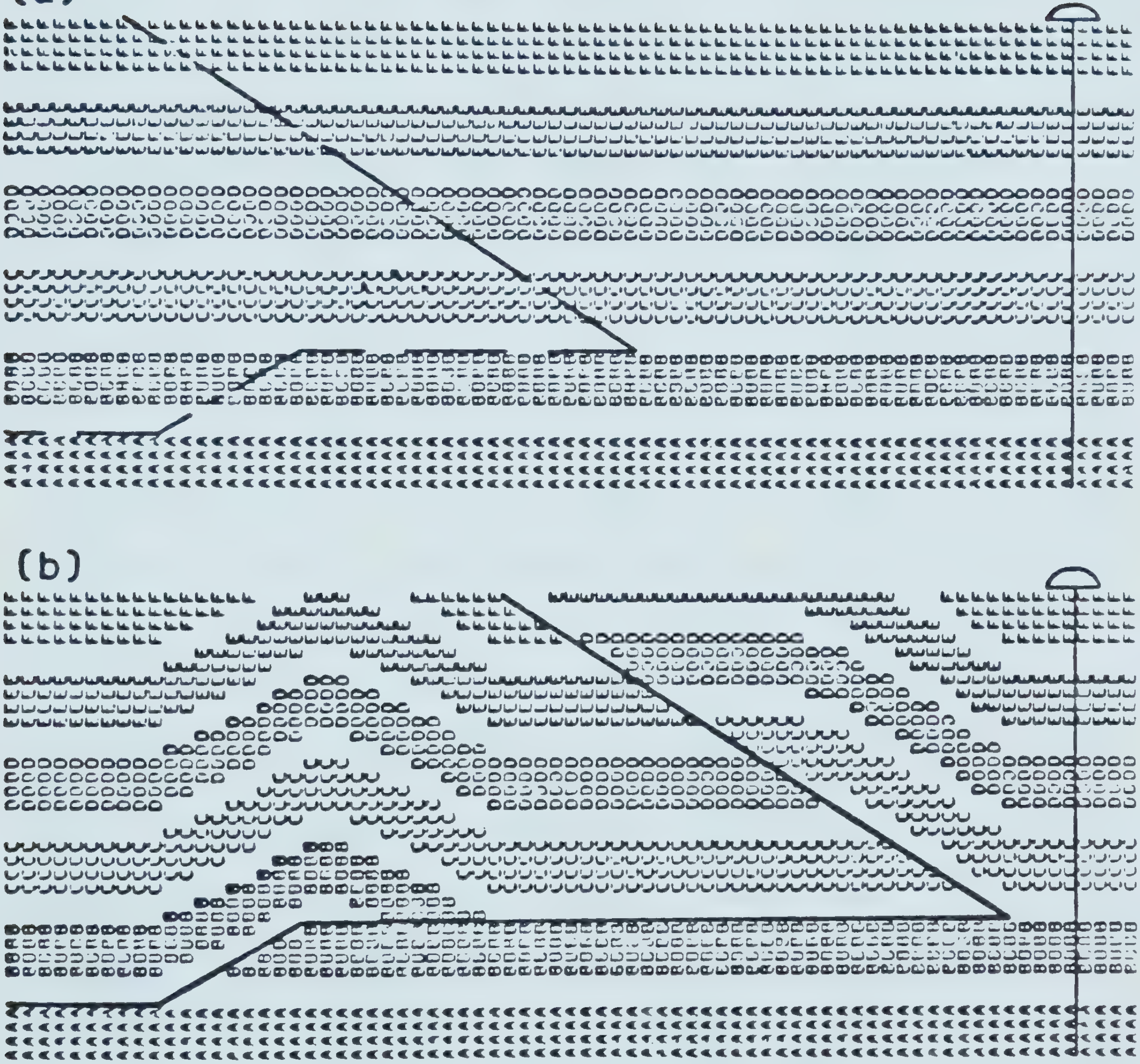


Figure 4. Synthetic, machine-constructed, model cross-sections showing the essential features of an intercutaneous wedge. The lines in (a) show the initial positions of the lower and upper faults of a wedge. Those in (b) show the positions of the bounding faults after the wedge has moved some distance towards the foreland.

foreland on the right; the vertical lines represent pin lines. Figure 4 shows that, like most northeast-verging thrusts in the Foothills, the lower bounding fault of a wedge probably consisted of flats and ramps. The uppermost segment of the lower bounding fault was horizontal and was overlain by a hangingwall flat. This suggests that the wedge moved horizontally towards the northeast (Charlesworth and Gagnon, 1985).

The upper bounding fault is unusual in that while active it actually moves towards the foreland and is always overlain by autochthonous strata. Movement of the wedge towards the foreland rotated strata formerly above and beyond the wedges extremity into parallelism with the upper bounding fault. As well, the width of the upper footwall flat of the lower fault increases with displacement (Charlesworth and Gagnon, 1985).

Older wedges are commonly tilted or folded by movement over ramps in underlying, younger thrusts that are themselves the lower faults of other wedges. Figure 5 is a synthetic, computer-generated model block diagram of the extremity of a rotated, west-dipping, south-plunging, wedge being unroofed by erosion.

Periodically throughout orogenesis the faults bounding the active wedge are replaced. The new wedge may incorporate all or part of the old wedge, or develop entirely within the old wedge. What principles control the development of the new bounding thrusts?

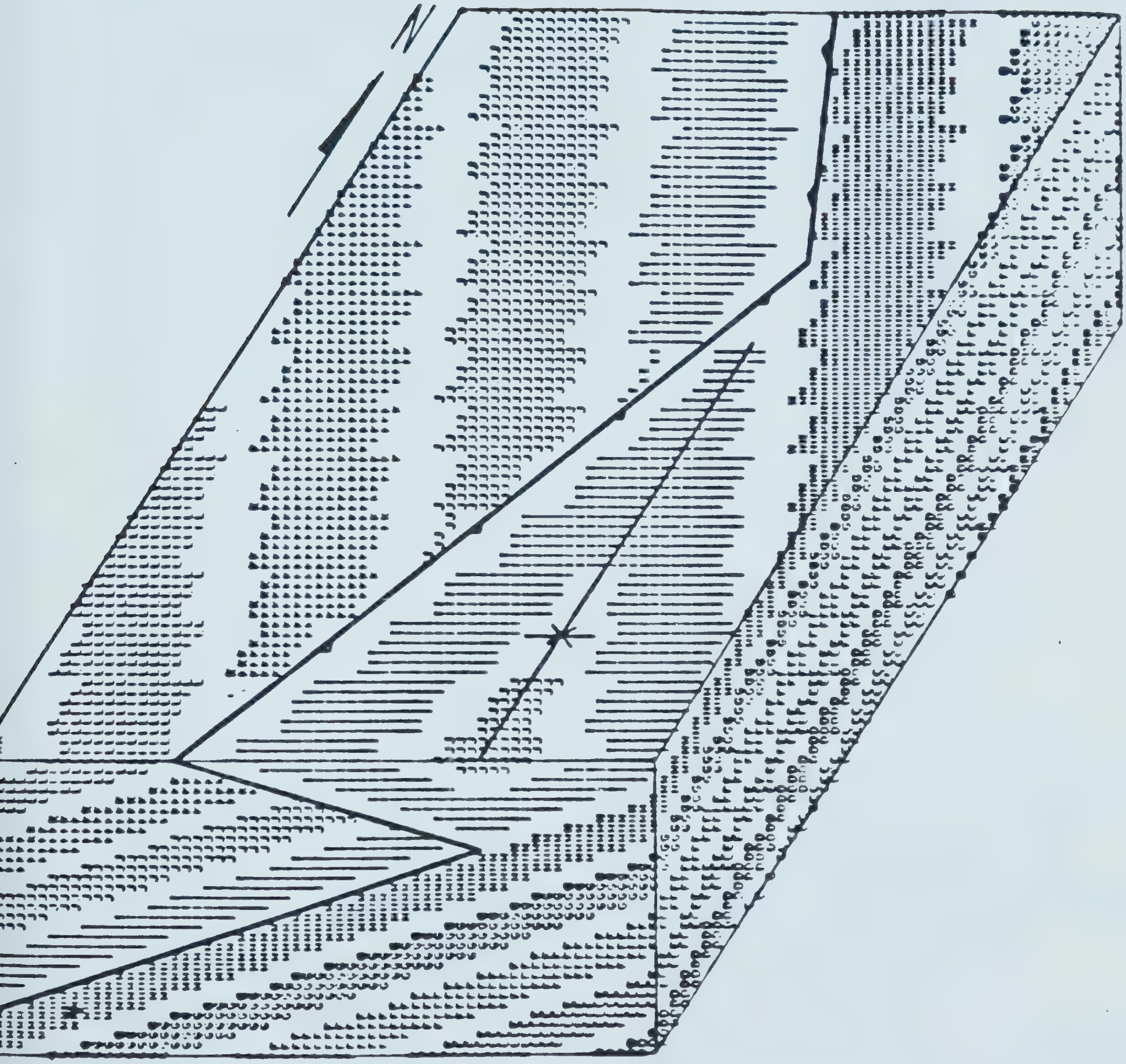


Figure 5. A synthetic, machine-constructed, model block diagram of the extremity of a west-dipping, south-plunging intercutaneous wedge being unroofed by erosion.

As a wedge moves towards the foreland, the highest footwall flat of the lower thrust widens (Fig. 4), a situation that cannot continue indefinitely. Figure 6 illustrates one way in which the width of this flat may be reduced: a new upper fault ending downwards against the lower fault of the old wedge develops inside the old upper fault. Note that the new upper fault has cut off some of the old wedge, which then reverts to being part of the foreland. Thus the most internal of a series of hinterland-verging splays from a common foreland-verging thrust is likely to be the youngest - the converse of the situation where the splays are foreland-verging.

Eventually the lower fault of the active wedge is replaced, usually by one in a lower stratigraphic horizon. When this happens, the new upper fault can be (b) inside, (c) continuous with, or (d) outside the old upper fault (Fig. 7). Whereas in (c) and (d) the new wedge completely encloses the old one, in (b) the new upper fault cuts off some of the old wedge which then reverts to being part of the foreland. Figure 8 is a model of the west-dipping, south-plunging extremities of wedges similar to those in Figure 7 (b), being unroofed by erosion. The presence of frontal ramps in younger lower faults and the tendency for these faults to cut up or down section when traced longitudinally are responsible for the dip and plunge of older wedges in the triangle zone.

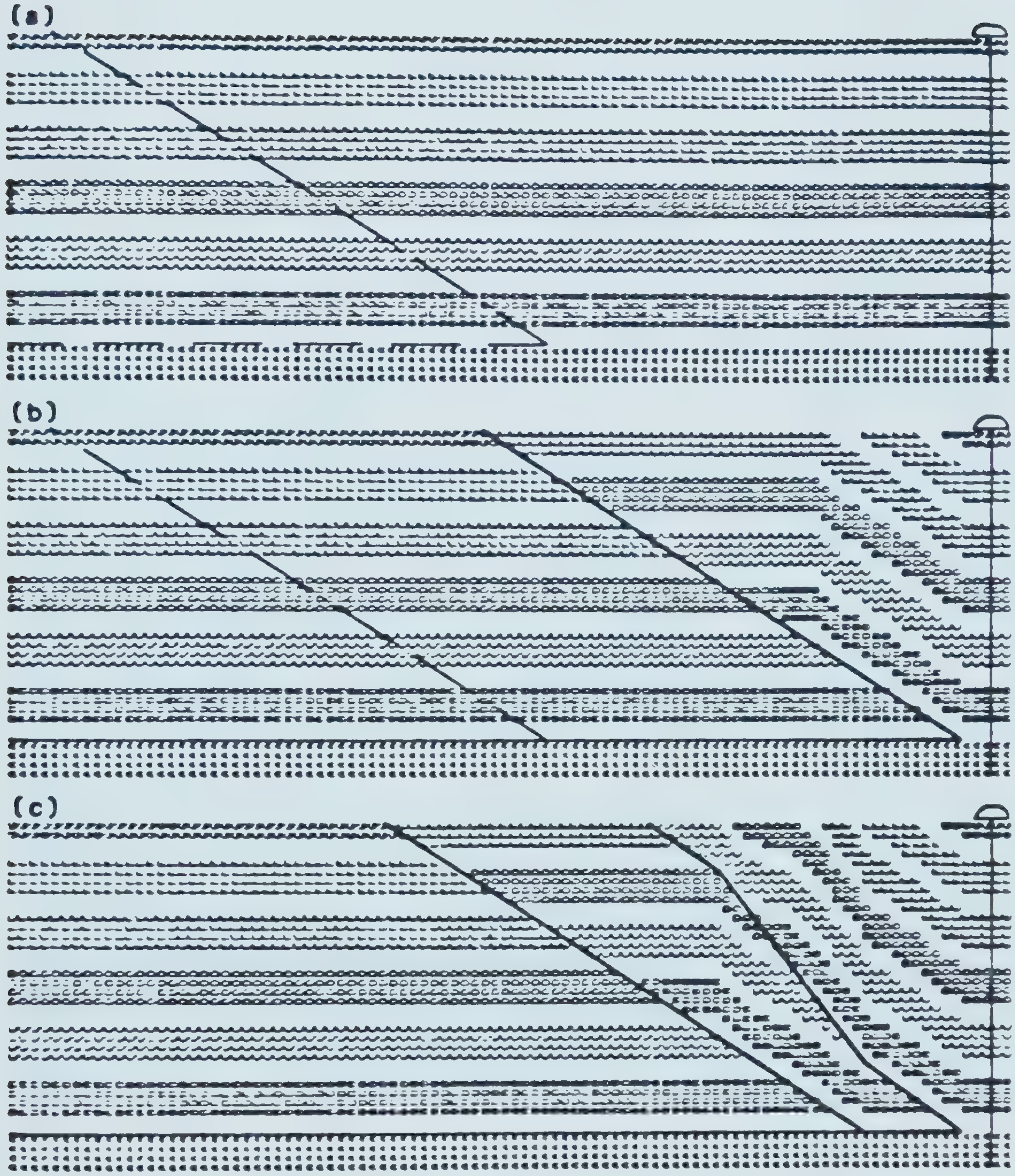


Figure 6. Model cross-sections showing the likely relationship between successive upper faults of wedges with a common lower fault. (a) The initial positions of the bounding faults of the wedge. (b) The solid lines represent the positions of these faults at the stage where, because of the increased length of the lower fault, the upper fault is replaced. The initial position of the new upper fault is represented by the broken line. (c) The situation after some movement of the new wedge towards the foreland.

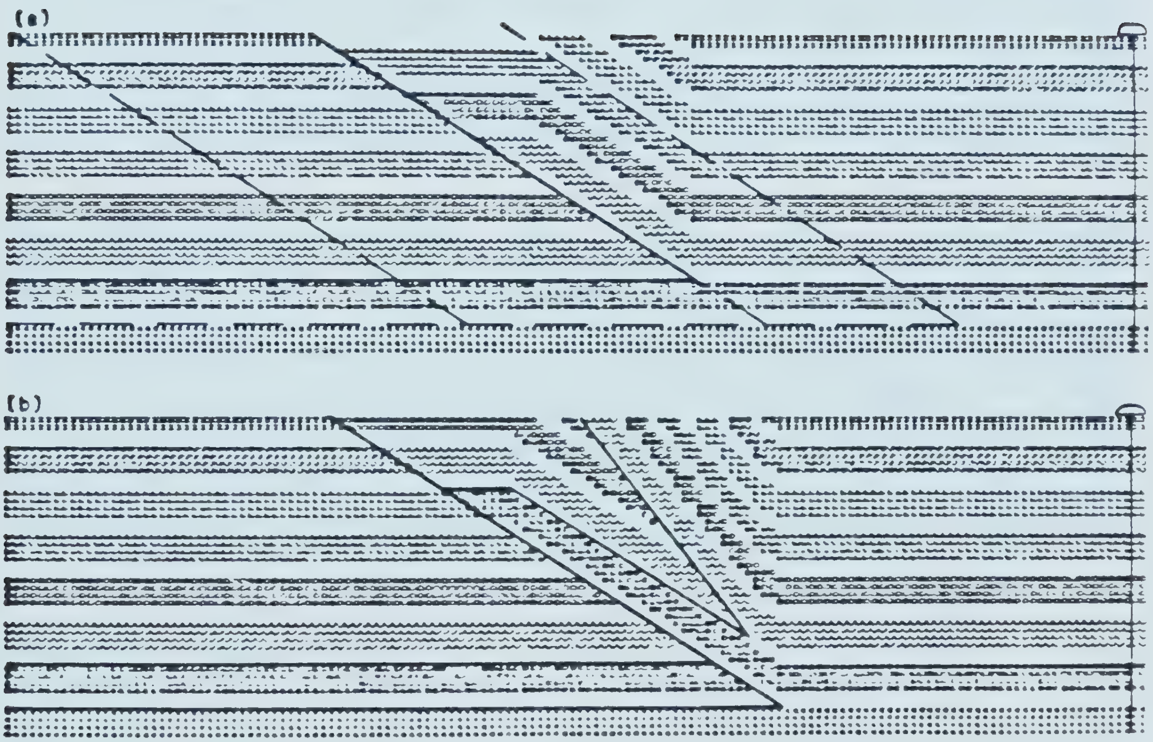


Figure 7. For caption see next page.

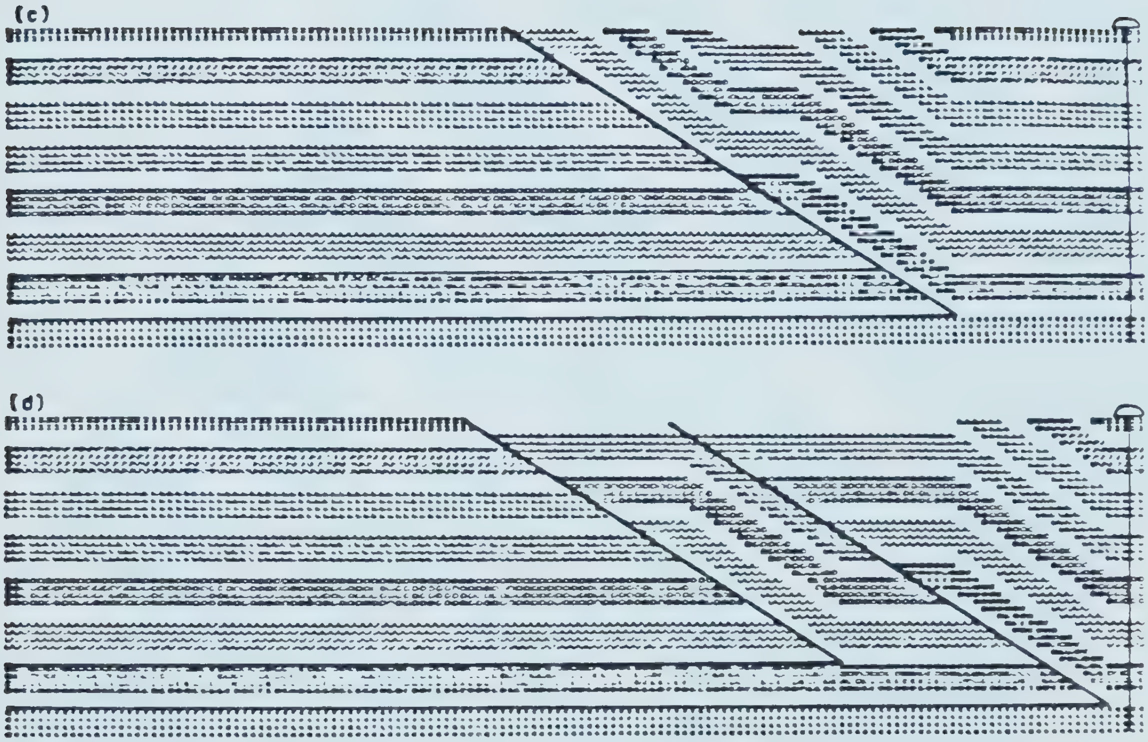


Figure 7. Model cross-sections showing the three possible positions of the new upper fault when the lower fault of an intercutaneous wedge is replaced. (a) The bounding faults of the old wedge are represented by solid lines. Broken lines indicate the initial positions of the new lower fault and the new upper faults of the wedges in (b), (c) and (d). In (b), (c) and (d) the upper fault of the new wedge is inside, continuous with, and outside the old upper fault, respectively.

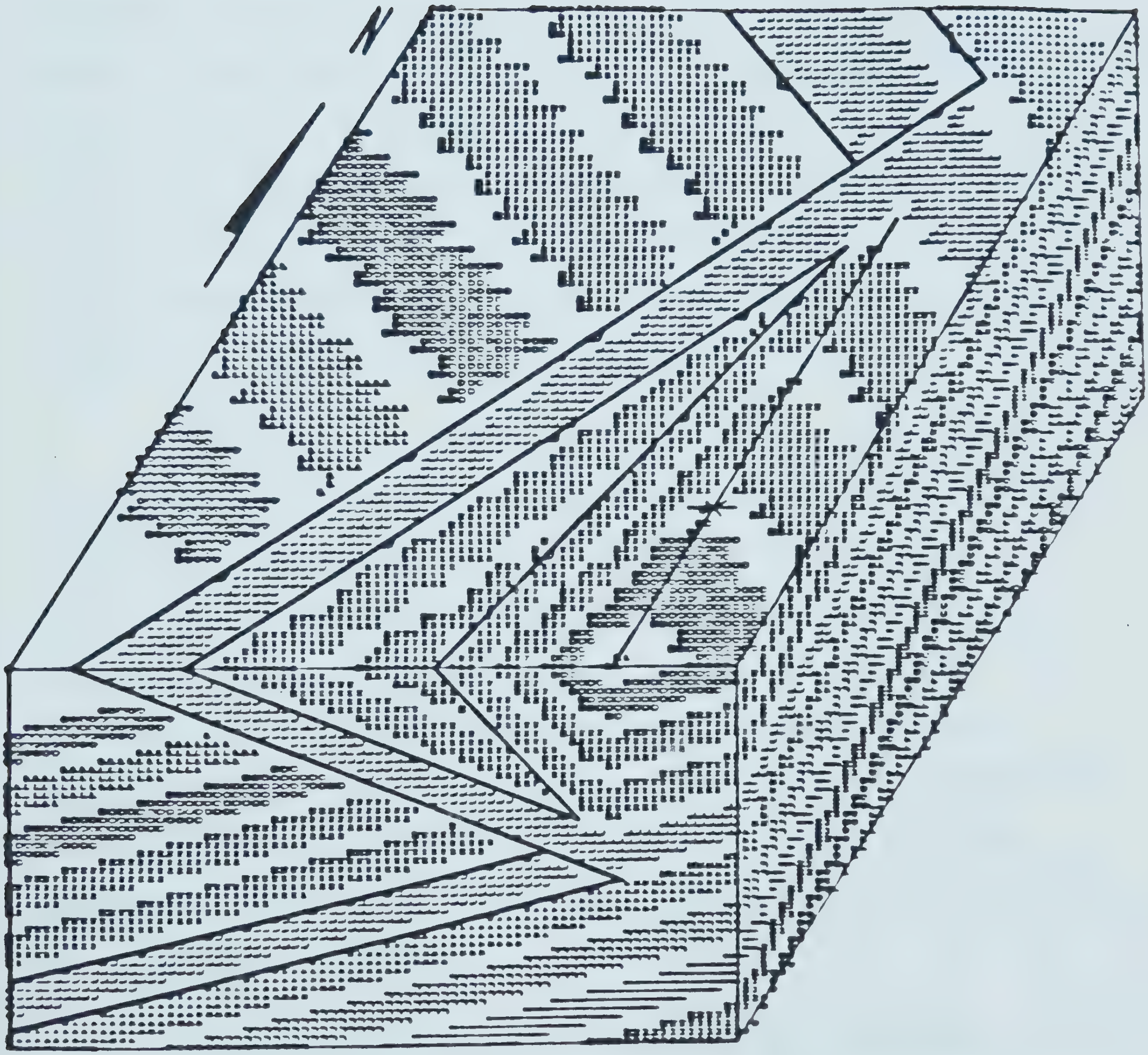


Figure 8. A model block diagram of the west-dipping, south-plunging extremities of wedges similar to those in Figure 7 (b), being unroofed by erosion.

EVOLUTION OF THE TRIANGLE ZONE NEAR COALSPUR, ALBERTA

In the Coalspur region, the northeast-dipping, southwest-verging Pedley Thrust separates the triangle zone from the southwest limb of the Alberta Syncline (Fig. 9, in pocket). The Pedley Thrust fault was first recognized and mapped in the Coalspur region by MacKay (1943). Mapping by Price et. al. (1977) revealed that the fault extends northwest to the Athabasca River. Jones (1982) showed a seismic profile run near Robb which clearly displayed the southwest limb of the Alberta Syncline and the underlying Pedley Thrust.

The trace of the Pedley Thrust crosses Highway 47 about 4.5 km southwest of Robb. Outcropping 25 m northeast of the trace are approximately 35 m of fine-grained, light greenish-grey sandstone, evenly interbedded on a 20 cm scale with grey shales. These sandstones have been deformed into a series of tight anticlines separated by steeply northeast dipping faults. The anticlines have a wavelength of about 10 m and an amplitude of 6 m. Their fold axes plunge 2° to the southeast. Their axial planes dip steeply northeast indicating a southwesterly vergence.

Strata outcropping 50 m further to the southwest dip to the southwest at about 20 and lie in the footwall of the Pedley Thrust. The trace of the fault plane is recessive and forms a covered interval between the two outcrops. The folds found in the immediate hangingwall are probably fault drag folds, and as mentioned above, they indicate a southwesterly vergence.

Palynological data indicate that the folded strata in the hangingwall of the Pedley Fault are latest Campanian to earliest Maastrichtian (Jerzykiewicz and Langenberg, 1983). These Brazeau Formation sands and shales are probably equivalent to the Bearpaw Formation of the Plains, although they contain no marine fossils (A. Sweet, pers. comm., 1985). Strata in the immediate footwall are early to middle Maastrichtian (Jerzykiewicz and Langenberg, 1983). The occurrence of older strata in the hangingwall lying on younger strata in the footwall also supports a southwesterly vergence along the Pedley Thrust Fault.

Elsewhere placement of the fault trace was based on the following factors:

1) The trace of the fault lies northeast of regional southwest dips and southwest of regional northeast dips.

2) The topography northeast of the fault is characterized by long, gently dipping, northeast-facing slopes and short, steeply dipping southwest-facing slopes. Conversely, southwest of the fault the southwest-facing slopes are long and gently dipping, while the northeast-facing slopes are short and steep.

3) The fault trace is generally a recessive feature, occupying valleys and low lying areas.

Southeast of the Embarras River the topographic high

immediately northeast of the trace of the Pedley Thrust is underlain by a cliff forming horizon (Fig. 9). This horizon is one of the more persistent of the conglomeratic horizons within the Lower Brazeau Formation (Jerzykiewicz, pers. comm., 1985). The conglomerate is commonly moderate red in color, cross bedded, and is mainly composed of black, red and white chert and quartzite pebbles. The pebbles are usually well rounded and supported by a coarse quartz-litharenitic sand matrix. The conglomerate frequently grades laterally into coarse quartz-litharenitic sandstone.

The strike of the Pedley thrust changes gradually from about 130° at the southeast end of the study area to less than 100° at the northwest end (Fig. 9). A sharp change in topography is visible at the northwest end of the study area. The topographic highs and lows in both the footwall and hangingwall of the Pedley Thrust, which maintain a fairly uniform appearance throughout the rest of study area, are replaced by a physiographic depression, 15 km wide measured looking due north, with negligible relief and very little outcrop.

Strata above the Pedley Thrust along the Embarras River are essentially planar and are probably parallel to it. Dips range from 20 to 60° but are usually about 42 or 43°. Coal seams identified northeast of the Pedley Thrust include the Val D'or, Arbour and Silkstone seams. The Val D'or and Arbour coal seams outcrop in an old mining pit 4.5 km northwest of Robb. The trace of the seams can be followed along strike to

the southeast into the Robb township. Southeast of Robb the topographic high associated with the outcrop of the seams can be readily followed on air photos (Fig. 9).

The only other coal seams positively identified in the Pedley thrust sheet are the Silkstone seams. These seams outcrop 2 km southwest of Robb along the Embarras River. The Val D'or-Silkstone interval is 220 m thick. Drillhole data indicates that the Mynheer seam lies 46 m below the Silkstone seams at Robb (R.F.Engler, pers. comm., 1985). Other outcrops of coal were mapped but were not positively identified.

Southwest of the Pedley Thrust, within the triangle zone, the remnants of eight intercutaneous wedges can be recognized. These wedges are the four Mynheer wedges, the two Val D'or wedges, the Lower Brazeau wedge and the Pedley wedge. Generally, each wedge is named after the highest horizon followed by its lower fault. The wedges will be treated in the order in which they originally evolved with one exception. Although they developed after the Val D'or wedges, the Mynheer wedges will be treated first as they are the best exposed and least deformed of all the wedges. As such they best illustrate the idea intercutaneous wedge.

The Mynheer Wedges

Between the Pedley Thrust and the Railhead Fault Zone, which includes the Sterco Thrust (Fig. 9), the Mynheer coal seam dips southwest, displays complex internal folding and

faulting on a mesoscopic scale, and contains the northeast-verging Coal Valley Thrust (Charlesworth and Gagnon, 1985). Good outcrops of the structurally disrupted Mynheer seam occur at the Luscar-Sterco Coal Valley Mine, where it is exposed in open pits, and on Jackson Creek, less than 1 km north of the Embarras River. Elsewhere the Coal Valley Thrust is recognized by the disturbed nature of the log signiture of the Mynheer seam where it houses the Coal Valley thrust fault (Fig. 10).

Southeast of the Railhead fault zone, the seam is gently folded and lacks internal deformation (Figs. 11, 12). The thrusts in the Railhead fault zone dip northeast (see e.g. Fig. 12) and, as indicated by fault drag and by their cutting up section to the southwest in the footwall, verge southwest (Gagnon, 1982; Charlesworth and Gagnon, 1985).

Comparison of the relationships displayed in Figures 9, 11, and 12 with those displayed in Figure 5 suggests that the Coal Valley Thrust and the Railhead fault zone are the lower and upper faults of a southwest-dipping, southeast-plunging intercutaneous wedge. This is the Mynheer wedge.

Near the extremity of the wedge, the thickness of the Mynheer coal seam is up to 20 times its stratigraphic thickness of 4.2 m. This thickening is the result of (1) replacement of the lower thrust by duplexes whose roof and floor thrusts are within the seam, and (2) vertical stacking of these duplexes predicted to occur at the extremities of intercutaneous

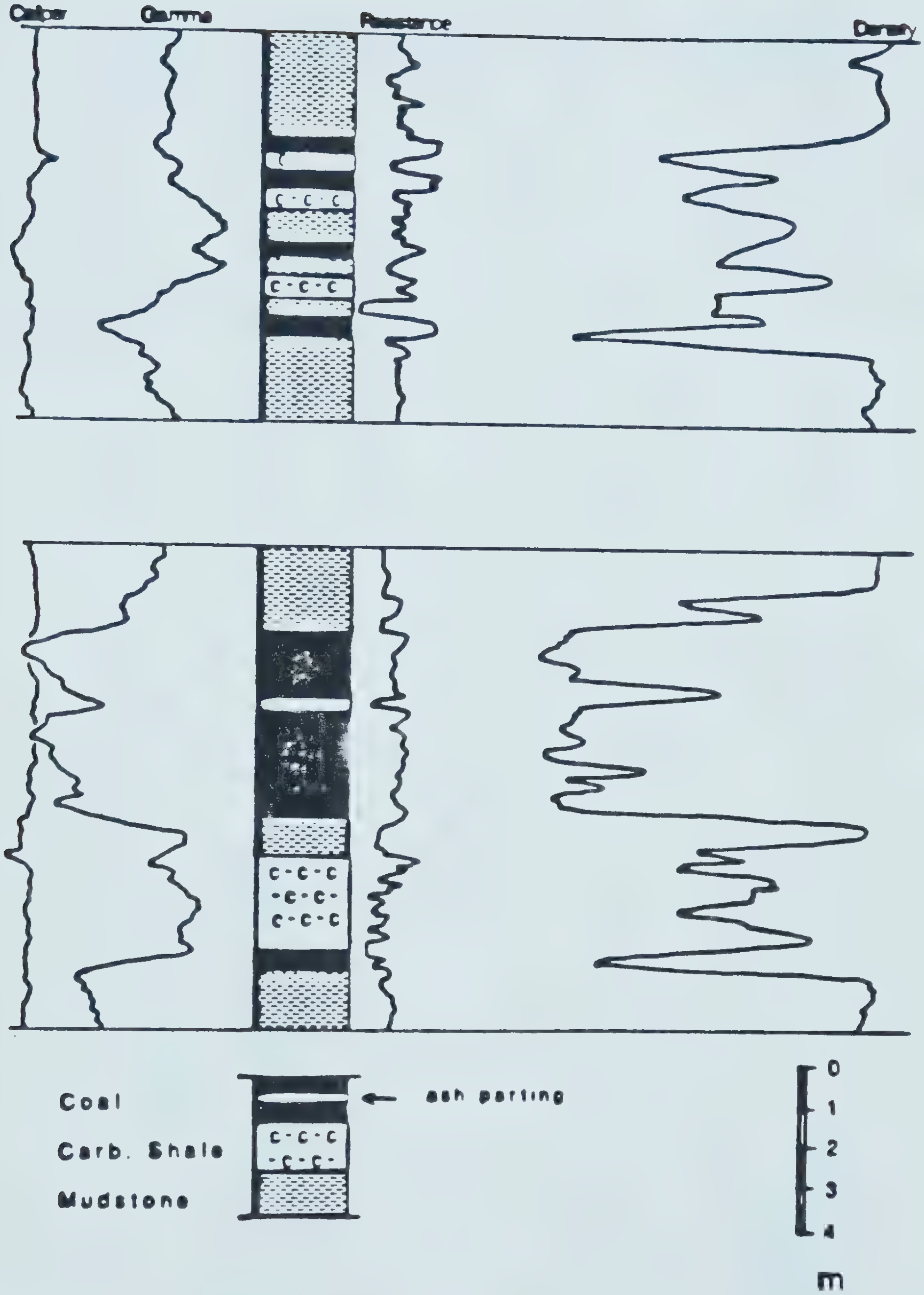


Figure 10. A comparison of the log signatures of the undisturbed Mynheer seam, at bottom, and the Mynheer seam where it houses the Coal Valley Thrust, at top.

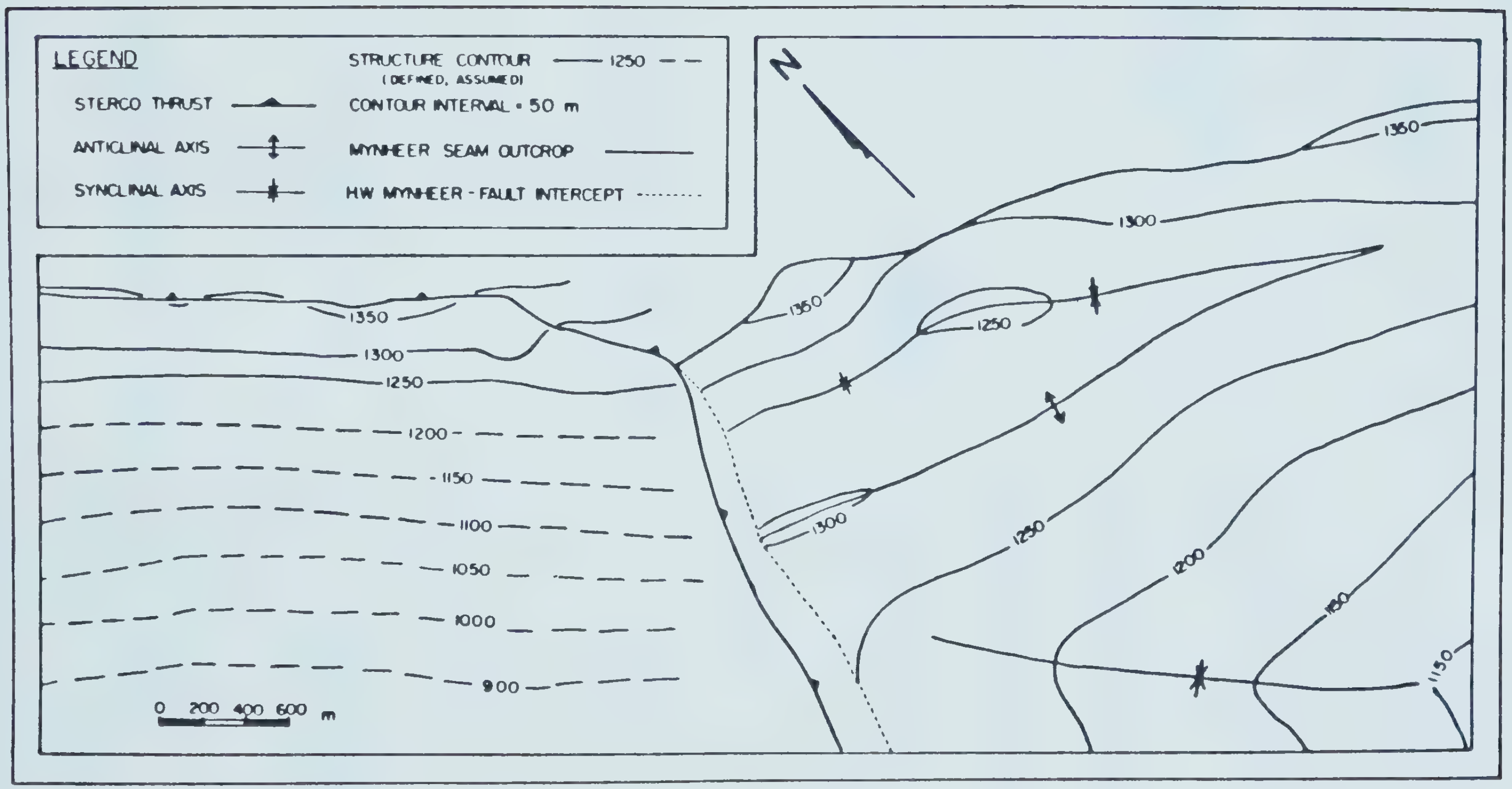


Figure 11. A structure contour map of the base of the Mynheer coal seam in an area of the Luscar - Sterco Coal Valley Mine. The location of this map is shown on Figure 9.

FIGURE 12

LEGEND

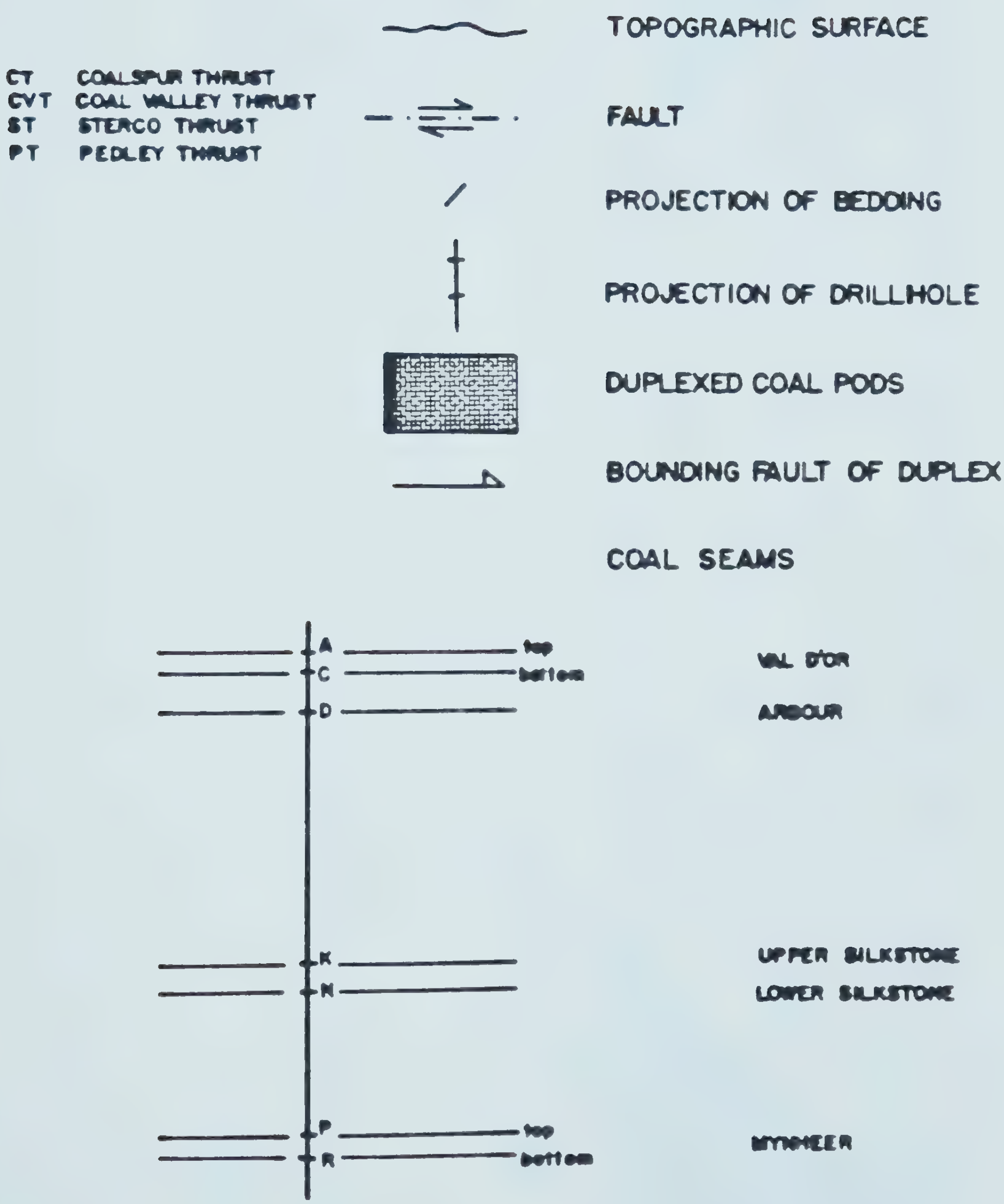
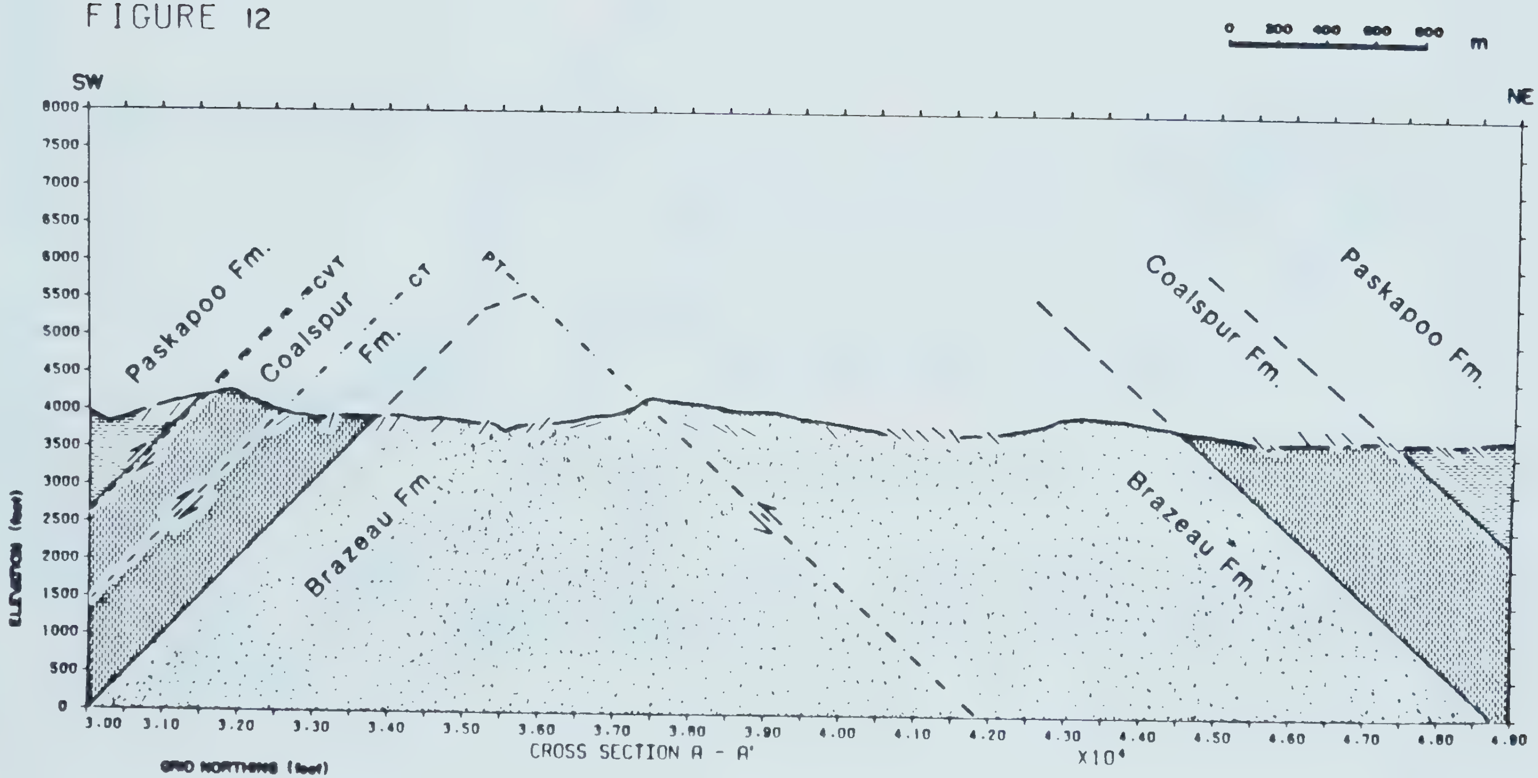


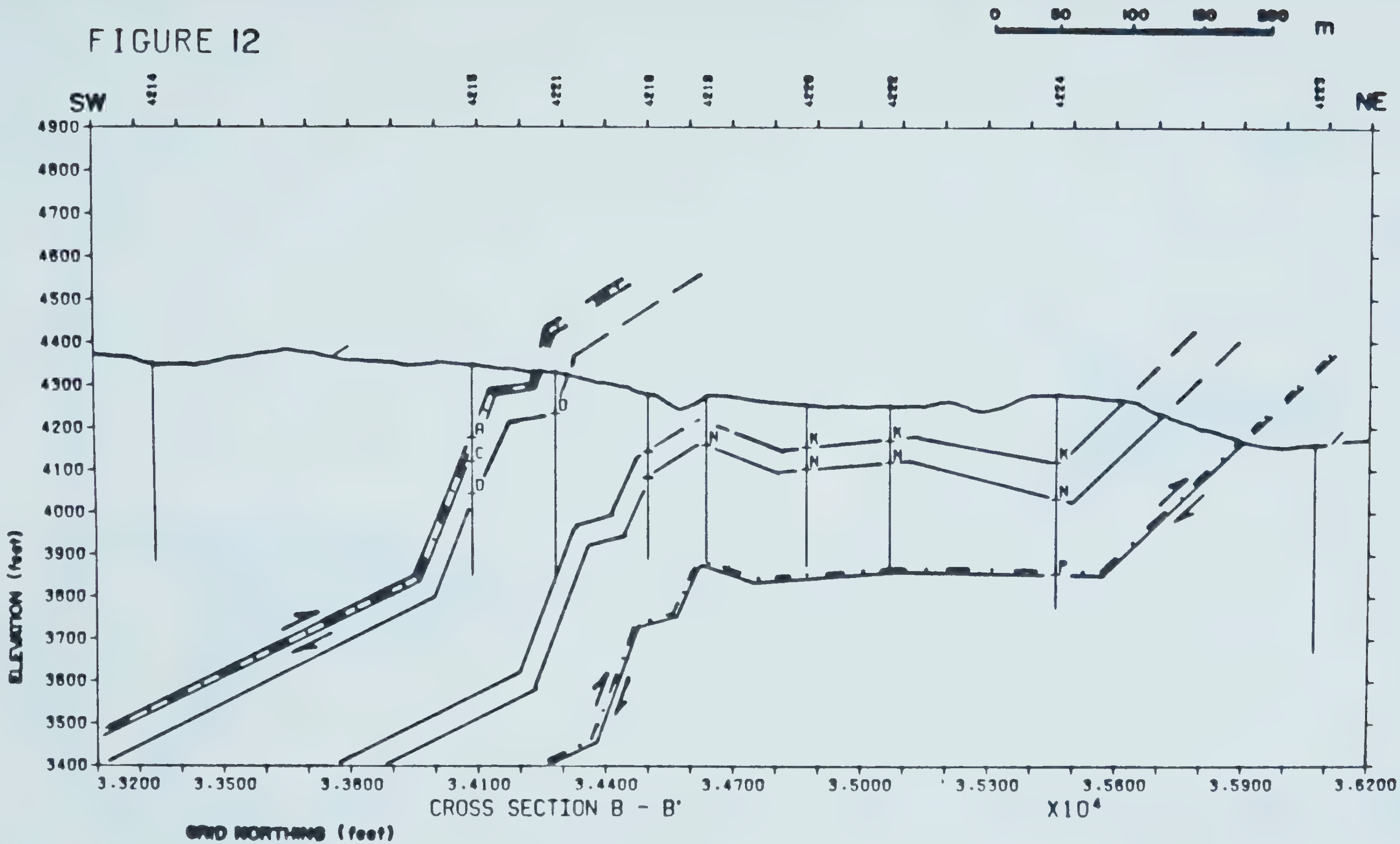
Figure 12. Cross-sections of the triangle zone near Coalspur. The locations of these sections are shown on Figure 9.

FIGURE 12



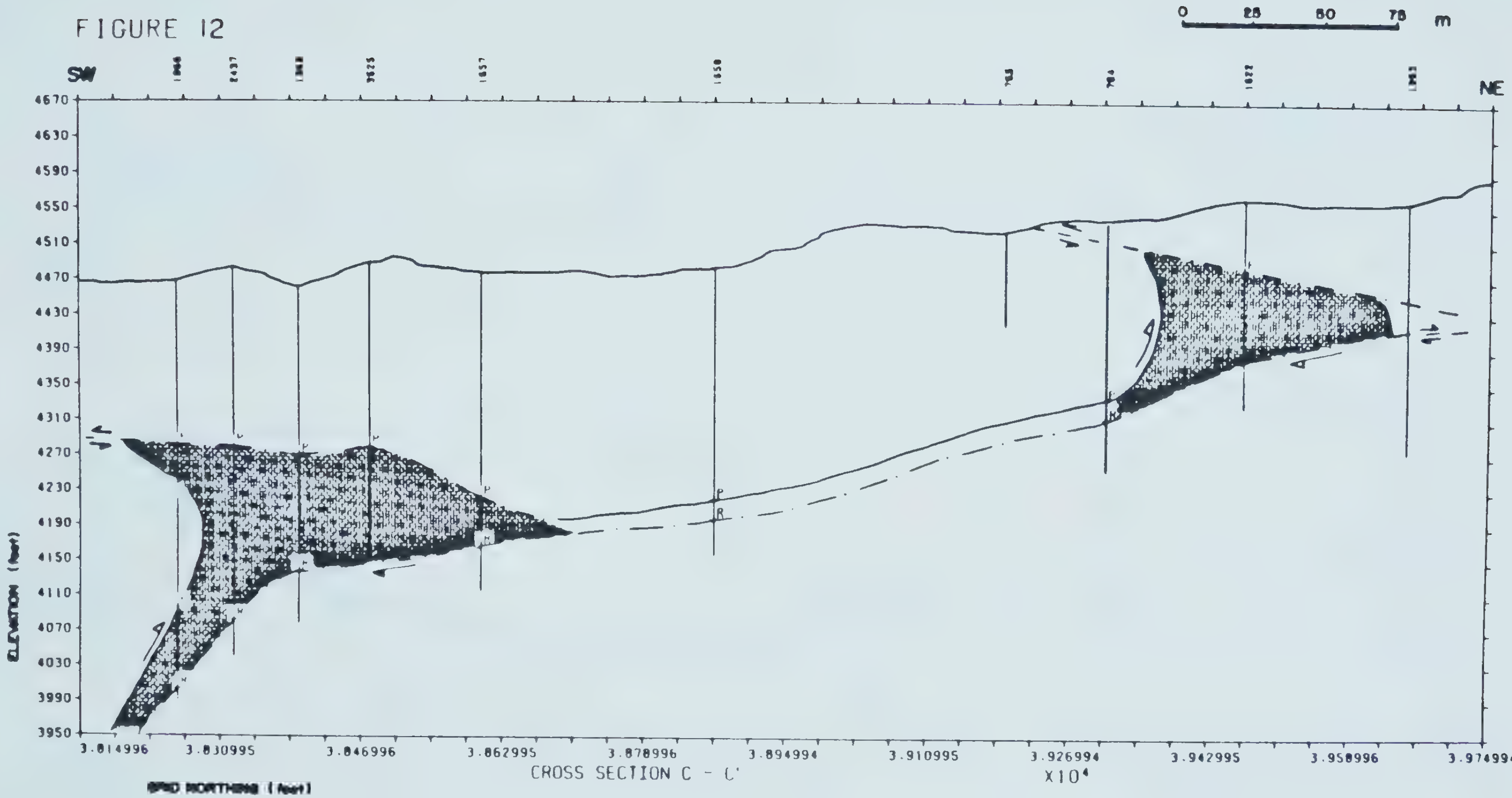
0 200 400 600 800 m
SW
NE
Paskapoo Fm.
CVT
Coalspur Fm.
CT
PT
Brazeau Fm.
Coalspur Fm.
Paskapoo Fm.
Brazeau Fm.
ELEVATION (feet)
8000 7500 7000 6500 6000 5500 5000 4500 4000 3500 3000 2500 2000 1500 1000 500 0
3.00 3.10 3.20 3.30 3.40 3.50 3.60 3.70 3.80 3.90 4.00 4.10 4.20 4.30 4.40 4.50 4.60 4.70 4.80 4.90
GRID NORTHING (feet)
CROSS SECTION A - A'
X10⁴

FIGURE 12



CROSS SECTION B - B'

FIGURE 12



0 25 50 75 m
SW
NE
4670
4630
4590
4550
4510
4470
4430
4390
4350
4310
4270
4230
4190
4150
4110
4070
4030
3990
3950
ELEVATION (feet)
P
R
3.814996
3.830995
3.846996
3.862995
3.878996
3.894994
3.910995
3.926994
3.942995
3.958996
3.974994
X10⁴
GRID NORTHING (feet)
CROSS SECTION C - C'

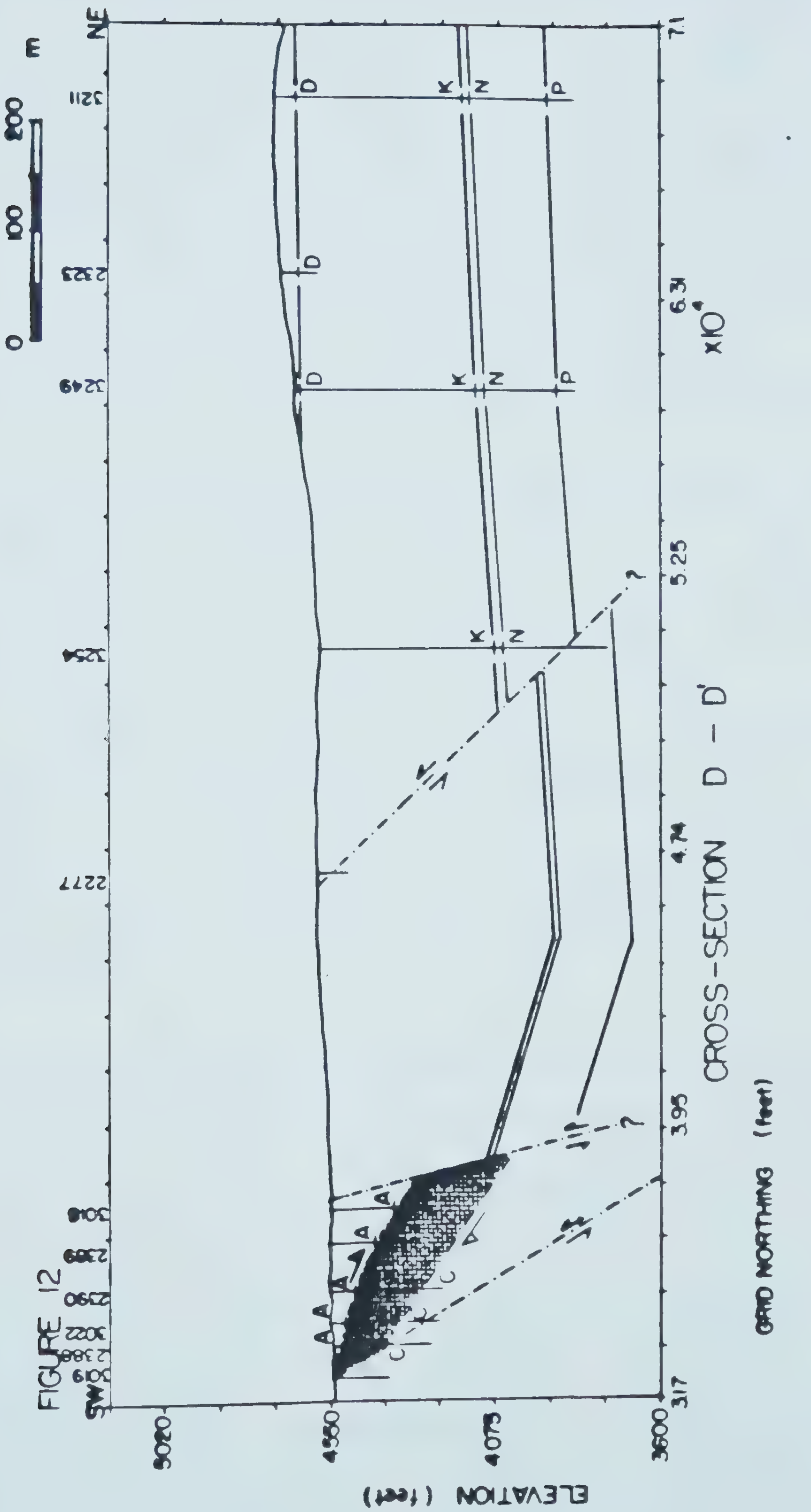


FIGURE 12
SW
NE
CROSS-SECTION D - D'
ELEVATION (feet)
GRID NORTHING (feet)
x10⁴
0 100 200 m
3.17
3.95
4.74
5.25
6.31
7.1
3600
4075
4550
5020
3019
2389
3022
2390
2389
3016
2277
3254
3249
2323
3211

wedges. Boyer and Elliot (1982) have shown that the total displacement of the strata above a duplex with respect strata below a duplex (S)is equal to A/t - W (S = A/t - W). In the above equation A is the cross-sectional area of the duplex, t is the stratigraphic thickness of the strata in the duplex, and W is the current width of the duplex. The cross-sectional area of the thickened Mynheer coal seam suggests a total displacement of about 2.5 km (Charlesworth and Gagnon, 1985).

The structure of the Mynheer wedge is, however, more complex than shown in Figures 4 and 5 (Fig. 9, 11, 12). First, there are four upper faults, that together form the Railhead fault zone, of which the Sterco Thrust is the most external. Although only the Sterco Thrust is exposed in open pits, the presence of the others is suggested by the configuration of the Upper Silkstone coal seam revealed by drillhole data and by the occurrence of thickened Mynheer coal in elongate pods.

There are four distinct pods of thickened Mynheer coal (Fig 9, 12), each of which apparently coincides with the intersection of one of the northeast-dipping thrusts with the Coal Valley Thrust. The most internal thrust apparently truncates the Val D'or seam in the abandoned underground Foothills Mine. As predicted by the models of Figures 4 and 5, strata immediately above the Mynheer seam form the hangingwalls of all but the most external of the four thrusts - this fault, the Sterco Thrust, is discussed below.

The four Mynheer wedges probably developed along the lines indicated in Figure 6, i.e. the most internal thrust is the youngest. If the thrusts had developed from southwest to northeast, the spacing between each active thrust and its internal predecessor would have remained the same throughout orogenesis. If, on the other hand, they had developed from northeast to southwest, the spacing between each active thrust and its predecessor would have decreased. A new upper fault is unlikely to develop close to its predecessor so, because the thrusts are closely spaced today, the thrusts probably developed from northeast to southwest.

A second complexity in the structure of the Mynheer wedge system is the existence of Brazeau strata much older than the Mynheer seam in the hangingwall of the Sterco Thrust. This fault appears to have coincided with the upper fault of another wedge whose lower bounding fault is situated in an older horizon. This wedge, the Lower Brazeau Wedge is discussed below.

Val D'or wedges

Between the Pedley Thrust and the Sterco fault zone, the Val D'or coal seam generally dips southwest, is internally deformed and contains the Coalspur Thrust (Fig. 9). A good outcrop of the structurally disrupted Val D'or seam occurs in a road cut on Highway 47 at Coalspur. Bedding dips 55^{o} due southwest here paralleled by the Coalspur Thrust which repeats part of the Val D'or seam. The fault is housed just above the

2 m sandstone split within the Val D'or seam. Val D'or coal found in the hangingwall of this thrust is on fire. The fire has baked the overlying sandstones bright red and has caused the seam to recess approximately 10 m back from the face of the outcrop. The fire has been prevented from penetrating below the thrust fault by the presence of a 25 cm thick bentonitic fault gouge. Below the fault the strata are cut by numerous mesoscopic thrusts. These northeast-verging faults dip southwest from 0 to 90°, with offsets varying from 10 cm to 200 cm. These faults can usually be traced for a distance of 4 to 5 m measured in the direction of movement, and are replace upwards by complex northeast verging folds. Where the Val D'or seam does not outcrop, the Coalspur Thrust is recognized by the disturbed nature of the log signature of the Val D'or seam (Fig. 13).

The Coalspur Thrust is apparently the lower common fault of one or more intercutaneous wedges whose extremities were truncated by the upper bounding faults of the Mynheer wedges and the Lower Brazeau wedge. These Val D'or wedges are thus older than the Mynheer wedges and the Lower Brazeau wedge.

Southeast of the Railhead fault zone, the Val D'or seam lies in the broad Weldwood syncline (Figs. 9, 11, 12). Throughout the syncline, the seam is involved in a northeast-verging duplex (Fig. 14, 15). The roof and floor thrusts of the duplex sometimes coincide with the top and bottom of the seam. At other times only the top third of the

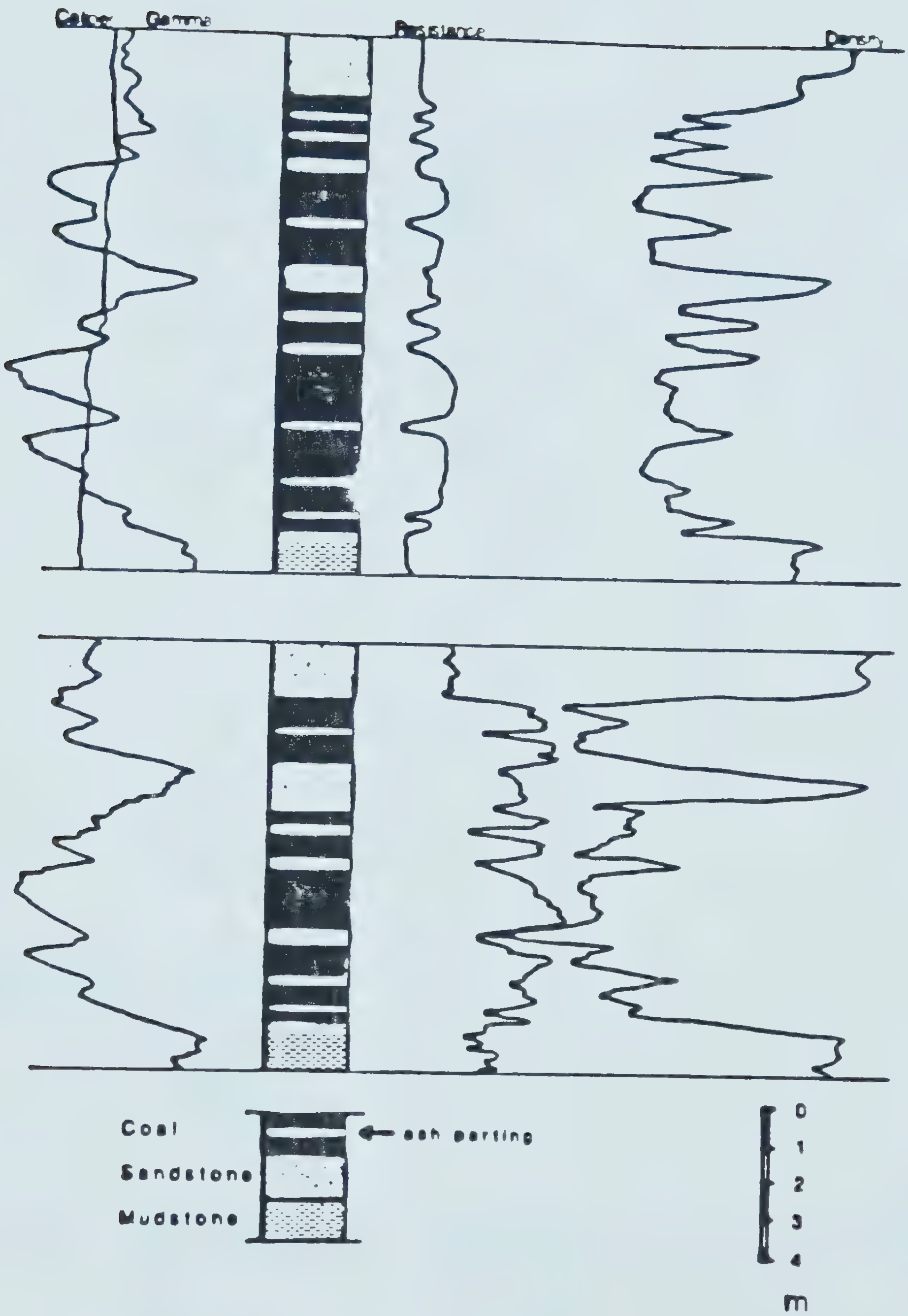


Figure 13. A comparison of the log signatures of the undisturbed Val D'or seam, at bottom, and the Val D'or seam where it houses the Coalspur Thrust, at top.

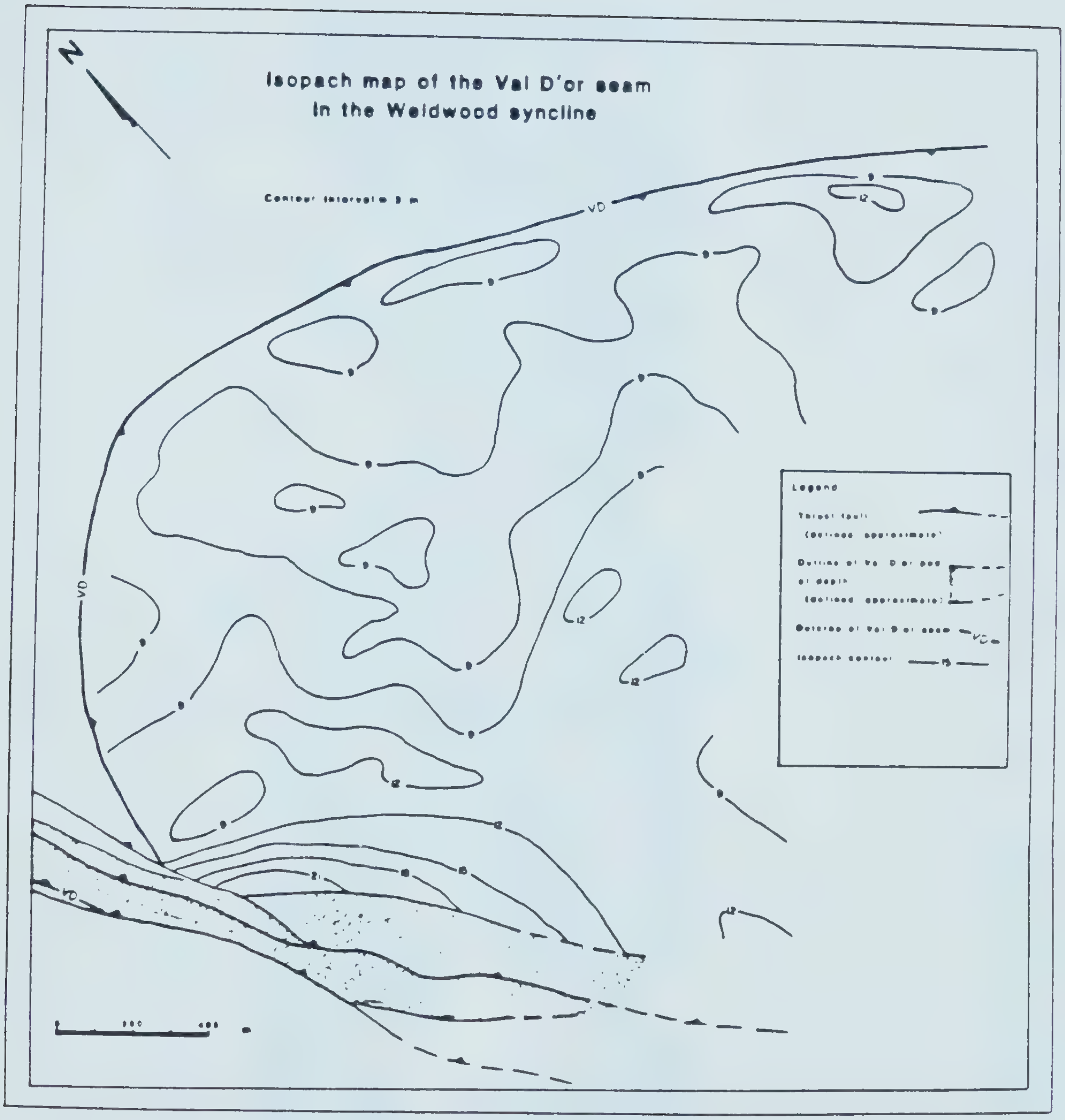


Figure 14. An isopach map of the thickness of the Val D'or seam in the Weldwood Syncline. The location of this map is shown on Figure 9.

Figure 15. A sketch of the Val D'or coal seam in the Weldwood syncline, where it is invovled in a duplex. The roof and floor thrust of the duplex coincide with the top and bottom of the coal seam in this sketch.

seam is involved in a duplex. The duplex appears to vary between these end members in apparently random fashion (Fig. 14). Thus the coal seam in the syncline contains a thrust that was originally continuous with the Coalspur Thrust and is the lower common fault of one or more intercutaneous wedges.

In part of the southwest limb of the Weldwood syncline the thickness of the Val D'or seam is over 20 times its stratigraphic thickness of 8 m (Fig. 12). Forming the northeast boundary of this thickened zone is a northeast-dipping thrust, apparently the upper fault of an intercutaneous wedge. This fault is, however, overlain by strata older than the associated lower bounding fault, and appears to have been reactivated, or, in other words, coincides with the upper fault of a younger wedge whose lower fault is situated in an older stratigraphic horizon.

Other thrusts of this type occur in the southwest limb of the Weldwood syncline. These reactivated faults generally dip between 55 to 75° to the northeast. These steep orientations are probably due to deformation of the originally much less steeply dipping faults by the emplacement of the Mynheer and Lower Brazeau wedges (see below). Since these reactivated faults are deformed by the Mynheer wedges they must have developed after stabilization of the Val D'or wedges, but before the development of the Mynheer wedges. Other than the separations produced by these younger thrusts, the structural configuration of the Val D'or seam described above and

summarized in Figures 9 and 12 is similar to that in the model of Figure 8. The northeast-dipping, southwest-verging thrust or thrusts against which the Coalspur Thrust ended towards the northeast have been eroded.

Towards the southwest the thickness of the Val D'or seam in the duplex that replaces the lower fault of the external Val D'or wedge increases to more than 18 m (Figs. 12, 14). This increase in thickness is related to the reactivation of the upper bounding fault of the internal Val D'or wedge. As the upper bounding fault cut down past the Val D'or seam it appears to have flattened out into the seam for a short distance. This has resulted in the presence of both northeast and southwest-verging structures within the seam for a distance of 250 m northeast of the Val D'or wedge.

Evidence for the relative ages of the upper faults of the Val D'or wedges is non-existent. Most likely, however, the relative ages are as indicated in Figure 6, i.e. the most internal fault is the youngest.

Lower Brazeau Wedge

As mentioned above the most external northeast-dipping fault in the Railhead Fault Zone, the Sterco Thrust, is overlain by Lower Brazeau strata. This is indicated by the presence of the Lower Brazeau Formation tuffaceous horizon outcropping just northeast of Coal Valley (Fig. 9) (Jerzykiewicz, 1985).

This tuff outcropping near Coal Valley was formerly known as the Coal Valley Tuff (Gagnon, 1982), and was thought to be correlative with the Saunders Tuff (Jerzykiewicz and Mclean, 1980). On the basis of this correlation Charlesworth and Gagnon (1985) assigned the strata in the hangingwall of the Railhead Fault Zone to the Lower Coalspur Formation. More recently however, Jerzykiewicz (1985), on the basis of detailed mapping along the Blackstone River, has recorrelated the tuff at Coal Valley with the 15 m thick tuffaceous and bentonitic horizon found in the Lower Brazeau Formation. As well, a Potassium-argon date indicates an age of 76 Ma$\pm$2.0 for the tuff (Jerzykiewicz, pers. comm., 1985). This places the tuff early in the Upper Campanian, around 10 Ma older than the Saunders tuff which is Upper Maastrichtian. It is on the basis of these data that strata above the Sterco Thrust have been assigned to the Lower Brazeau Formation.

The Sterco Thrust appears, therefore, to have been reactivated, or, in other words, has coincided with the upper fault of a younger wedge whose lower bounding fault is situated in the Lower Brazeau Formation. The lower bounding fault of the Lower Brazeau wedge must be at least 600 m below the Mynheer seam in order to bring up the tuff. If the fault to footwall bedding angle is 30° it can be seen from Figure 4 that the minimum displacement of the wedge towards the foreland was about 700 m.

The Lower Brazeau Wedge apparently developed

contemporaneously with or slightly after stabilization of the initial Mynheer wedge. Contemporaneous with movement of the Lower Brazeau Wedge towards the foreland was the development of the remaining 3 Mynheer Wedges. These wedges developed entirely beneath the upper bounding fault of the Lower Brazeau Wedge, and behind the initial Mynheer Wedge. The most conspicuous structural feature southeast of the Sterco Thrust, namely the Weldwood syncline, is apparently a hangingwall syncline developed during the emplacement of the Lower Brazeau wedge.

The upper bounding fault of the Lower Brazeau wedge appears to be folded. The strike of the fault varies from almost true north northwest of Coal Valley to almost due northwest alongside the surface exposure of the thickened Mynheer seam. Southeast of the most external Mynheer pod the fault strikes north-northeast. Strata both above and below the fault are not, however, folded with the fault. This suggests that the fault developed with a curved configuration. Frontal ramps in the lower fault of the Lower Brazeau Wedge or possibly the cutting up or down section of the lower fault when traced longitudinally may be responsible for the curvature of the upper bounding fault.

The 1300 m interval between the truncation of the Lower Brazeau tuffaceous horizon in the hangingwall of the upper bounding fault of the Lower Brazeau wedge and the truncation of the Mynheer seam in the hangingwall, measured horizontally at

the topographic surface, indicates a local plunge of about 20 to the southeast. An anticline in the hangingwall of the Sterco Thrust, adjacent to where the tuffaceous horizon is truncated, exhibits a 15^{o} plunge due south. This is a good indication that, locally, steep plunges are present.

As mentioned above, strata in the hangingwall of the Sterco Thrust are folded. These folds affect the Mynheer seam (Fig. 11) and probably developed during emplacement of the initial Mynheer wedge and the subsequent Lower Brazeau wedge.

The Pedley Wedge

Towards the end of orogenesis the active wedge, which incorporated all or parts of the older wedges described above, appears to have been one whose upper fault is the Pedley Thrust. There are, however, approximately 1400 m of Brazeau formation between the Pedley Fault and the base of the Coalspur formation in the hangingwall of the Pedley Fault. This interval of strata is much thicker than the 900 m measured for the total thickness of the Brazeau formation on the Blackstone River by Jerzykiewicz (1985). The interval between the Lower Brazeau tuffaceous horizon and the Mynheer seam measured at Coal Valley is slightly thinner than the same interval measured at the Blackstone River. This seems to indicate that the increased thickness of the formation is due to a stratigraphic thickening of the basal cylothem of the Brazeau Formation by at least 500 m.

Strata above the Pedley Thrust fault dip northeast at about 42 and, as in Figure 4, strata above the thrust probably parallel the fault plane. If the fault to bedding angle in the footwall is 30°, from Figure 4 it can be seen that the minimum displacement of this wedge towards the foreland was 3.4 km. The Pedley Thrust appears to have been oblique to the extremities of the Val D'or and Mynheer wedges, because northwest of Coalspur it cuts their lower faults (Fig. 9). The Pedley Thrust also truncates the upper bounding fault of the Lower Brazeau wedge near Sterco (Fig. 9). The Mynheer and Val D'or seams in the southwest limb of the Alberta syncline show no internal deformation, indicating that the extremities of the older wedges above the Pedley Thrust have been eroded.

Anticline-syncline fold pairs in the footwall of the Pedley Thrust affect the Coalspur and Paskapoo Formations as well as the Coalspur and Coal Valley Thrusts. Drillhole data indicate the presence of a syncline-anticline fold pair between Coalspur and Sterco (Figs. 9, 12). The axial traces of these folds parallel the strike of the strata. These folds first appear just southeast of Coalspur. Here the Val D'or seam, in the hinge of the syncline, forms the crest of a ridge. The syncline is asymmetric, upright and open, with an apical angle of close to 140°. Its axial plane dips 60 to 65° northeast. The anticline is also asymmetric and upright, but it is tighter with an apical angle of 110°. Its axial plane dips 55° to the northeast.

The northeast limb of the syncline dips 60° to the southwest while the common limb dips gently to the northeast. There is less control on the southwest limb of the anticline but it apparently dips about 45 to 50° to the southwest.

The folds appear to plunge to the southeast. Up plunge to the northwest they have apparently been removed by erosion. Downplunge, to the southeast, the folds can be traced for more than 6 km. The folds becomes gradually more open in this direction. The most northeasterly limb begins to dip less steeply to the southwest while the most southwesterly limb retains a fairly constant southwesterly dip. Just 2 km northwest of Sterco the strata are planar and dip 35° to the southwest.

Another fold, affecting the Brazeau Formation, occurs just southwest of the Pedley Fault on Highway 47 (Figs. 9, 12). The strata found in the northeast limb of this asymmetric anticline dip regularly to the southwest at 18°. The surface trace of the axial plane occurs 425 m southwest of the trace of the Pedley Fault. The southwest limb dips southwest at 50° resulting in an apical angle of 148°. The fold axis plunges 3° on a bearing of 307°. The dip direction and dip of the axial plane is $35^{\circ}55^{\circ}$.

Other folds occur within the Pedley wedge but remain unquantified due to the paucity of outcrops and the lack of comprehensive drilling data. The predominant style of the

folding appears to be chevron as indicated by the planarity of the fold limbs, the very narrow hinges and the convergent axial planes.

These folds were developed after the emplacement of the Val D'or and Mynheer wedges as indicated by the folding of the Coalspur and Coal Valley Thrusts. The folding probably occurred during the emplacement of the Pedley wedge as no similar folds are found northeast of the Pedley Thrust.

Other Wedges

Other wedges whose upper faults coincide with the Pedley Thrust may be present in the subsurface. In addition, along strike both northwest and southeast of Coalspur natural gas is being produced from Mississippian strata above a northeast-verging thrust. Although this fault may end at depth against the Pedley Thrust, it is possible that it ends against another foreland-dipping, hinterland-verging thrust that is northeast of the Pedley Thrust. As well, the Pedley fault and strata both in the hangingwall and footwall of the fault appear to be gently anticlinally folded (Fig. 12). This would appear to support the existence of another wedge northeast of the Pedley thrust.

SUMMARY AND CONCLUSIONS

Deformation in the Triangle Zone near Coalspur appears to have consisted of the emplacement of a series of intercutaneous wedges. The oldest deformational events saw the emplacement of at least two wedges with a common lower fault, the Coalspur Thrust, located within the Val D'or coal seam. The extremity of the western most wedge outcrops in the west limb of the Weldwood Syncline. The extremity of the other wedge has been eroded. In most places the Coalspur Thrust is represented by a duplex involving all or part of the seam. At the extremity of the western wedge, the thickness of the coal seam is up to 20 times the stratigraphic thickness. This thickening, the result of vertical stacking of duplexes involving the seam, can be expected to occur at the extremities of intercutaneous wedges.

The stabilization of the Val D'or wedges was followed by the development of four wedges with a common lower fault, the Coal Valley Thrust, within the Mynheer coal seam. At the extremities of these wedges the coal seam, as predicted, was thickened up to 20 times the stratigraphic thickness. The Mynheer wedges developed behind the extremities of the Val D'or wedges which then reverted to being part of the autochthonous foreland.

The upper fault of the initial, and thus the most external, Mynheer wedge coincided with the upper fault of a

wedge whose lower fault developed within the Lower Brazeau Formation. This Lower Brazeau wedge was active contemporaneously with Mynheer wedges.

Apparently the final deformational event was the development of a wedge whose upper bounding fault was the Pedley Thrust and which incorporated parts of the Val D'or, Mynheer, and Lower Brazeau wedge. Little is known about this wedge except that its lower bounding fault must occur 1400 m below the base of the Coalspur Formation as strata from this horizon are found outcropping just above the trace of the Pedley Thrust.

To summarize, it appears that deformation in the Coalspur area consisted of the emplacement of a series of intercutaneous wedges. Generally, the younger the wedge the older the stratigraphic horizon followed by its lower bounding fault. The similarity between the outcrop patterns predicted by a computer-modelling procedure and the outcrop patterns exhibited by the coal seams, and the occurrence of thickened coal at localities predicted by the model supports this conclusion.

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APPENDIX 1

FORTRAN PROGRAM CV-1

```
C
C INPUT
C
C OUTCROP LOCATION COORDINATES RECORDED WITH RESPECT TO UTM.
C
C OUTPUT
C
C OUTCROP LOCATION COORDINATES RECORDED WITH RESPECT TO THE
C LUSCAR-STERCO COAL VALLEY MINE GRID.
C
C PROCEDURE
C
C A CONTROL POINT WHOSE WHOSE UTM AND MINE GRID EASTING AND
C NORTHING ARE KNOWN, ALONG WITH THE ANGLE BETWEEN THE GRIDS,
C ARE USED TO ROTATE THE UTM GRID PARALLEL TO THE MINE GRID.
C

      REAL THETA
      INTEGER  TE,TN
      DATA THETA/.7982945/
      OPEN (5,file=' ')
      OPEN (6,file=' ')
C
C
      DO 30 I=1,13
          READ (5,*, END=40) TE,TN
          TEO=TE-516400.
          TNO=TN-5876425.
          TEO=TEO*3.28084
          TNO=TNO*3.28084
          GEO=(TEO*COS(THETA))-(TNO*SIN(THETA))
          GNO=(TEO*SIN(THETA))+(TNO*COS(THETA))
          GE=GEO+95044.07
          GN=GNO+33392.35
          WRITE (6,'(2F14.5)') GE,GN
   30 CONTINUE
   40 STOP
      END
```

APPENDIX 2
INSTRUCTION FILES FOR THE MACHINE-CONSTRUCTED MODEL CROSS-SECTIONS AND BLOCK DIAGRAMS.

Figure 4

```
STJ
Fig 4
1
N
N
36 76
N
N
N
Y
N
N
N
3 6
12 0
10 30
54 0
Y
35 21
12
Y
```

Figure 5

```
STJ
Fig 5
1
N
Y
31 82
N
Y
20
Y
31 78 10
N
N
N
Y
17 1
N
Y
1 4
82 0
Y
35 38
20
N
```

Figure 6

```
STJ
Fig 6
2
N
N
40 95
N
N
N
Y
N
N
N
1 6
95 0
Y
35 35
15
N
1 6
95 0
Y
35 45
15
Y
```

Figure 7A AND B

```
STJ
Fig 7
2
N
N
46 103
N
N
N
Y
N
N
N
1 12
103 0
Y
35 53
20
Y
1 6
103 0
Y
35 25
20
Y
```

Figure 7C

```
STJ
Fig 7C
2
N
N
46 133
N
N
N
N
N
N
1 12
133 0
Y
35 63
20
N
1 6
133 0
Y
35 75
35
Y
```

Figure 7D

```
STJ
Fig 7D
2
N
N
46 127
N
N
N
N
N
N
1 12
127 0
Y
35 79
20
N
1 6
127 0
Y
35 25
20
Y
```

Figure 8

```
STJ
Fig 8
2
N
Y
46 160
N
Y
15
Y
46 80 15
N
N
N
Y
45 35
Y
N
1 8
160 0
Y
35 73
20
N
1 2
160 0
Y
35 95
45
N
```

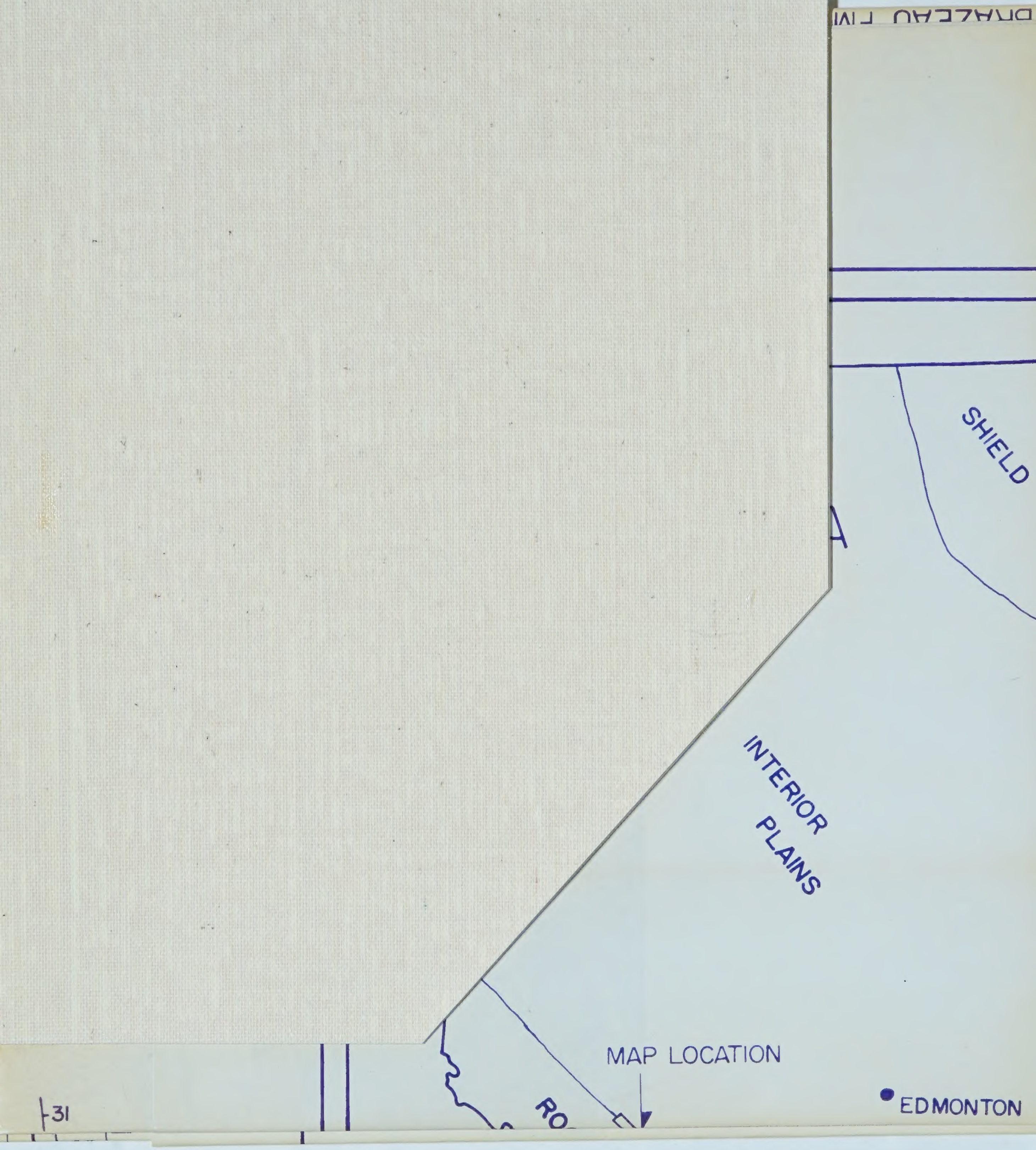
SHIELD
INTERIOR PLAINS
MAP LOCATION
EDMONTON
31

Figure 9. Geologic map of the Coalspur area. The Coal Valley thrust and the Coalspur thrust follow the Mynheer and Val D'or seams, respectively.